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ESKIMO IV

Magazine Separation Test

by
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and
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Test and Evaluation Directorate

MARCH 1977

Naval Weapons Center
CHINA LAKE, CALIFORNIA 93555

Department of Defense Explosives Safety Board
WASHINGTON, D.C. 20314

Naval Weapons Center

AN ACTIVITY OF THE NAVAL MATERIAL COMMAND

R. G. Freeman, III, RAdm., USN . . . . Commander

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FOREWORD

This report describes a full-scale magazine test conducted at the Naval Weapons Center in September 1975. The test work was conducted for the Department of Defense Explosives Safety Board (DDESB) using funds provided by that organization. The work was identified by Army Program Element Number 6.57.02.A and Project and Task Area Number 4A765702M857.

Based on data derived from the test, DDESB has made significant gains in information relating to hazards criteria.

This report has been reviewed for technical accuracy by DDESB staff members Mr. Russel G. Perkins and Dr. Thomas A. Zaker. Mr. Perkins and Dr. Zaker also played major roles in the design of the test.

Captain Peter F. Klein, USN, Chairman of DDESB, provided technical, administrative, and policy guidance during the preparation, execution, and reporting of the test.

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ESKIMO IV Magazine Separation Test, by F. H. Weals and C. H. Wilson. China Lake, Calif., Naval Weapons Center, 31 March 1977. 52 pp. (NWC 5873, publication UNCLASSIFIED.)

In an instrumented test in September 1975 at the Naval Weapons Center, approximately 37,000 pounds (16 783 kilograms) of trinitrotoluene (TNT) explosive contained in a hemisphere built of 8-pound (3.6-kilogram) blocks were detonated by means of an initiation system located at the center of the base of the hemisphere. The principal objective was to demonstrate the resistance of a newly designed headwall and door combination to blast simulating that possible at the minimum front-to-rear spacing now permitted for standard earth-covered magazines. The test demonstrated this headwall and door design to be well balanced and completely effective in preventing communication of explosion between magazines in a front-to-rear exposure at a distance in feet of 2.0 X $W^{1/3}$, where W is the weight in pounds of the high explosive that detonates.

Additionally, the results confirmed the ability of the single-leaf, sliding door to maintain its structural integrity whether mounted on a new structure or on an existing headwall. The results also demonstrated an imbalance in strength between this door and the existing headwalls built according to OCE standard drawing 33-15-64. The report contains data on igloo damage and structural motion and air-blast measurements at the site.

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INTRODUCTION

At the request of the Department of Defense Explosives Safety Board (DDESB), the Naval Weapons Center (NWC) in September 1975 conducted at the Randsburg Wash Test Range a large-scale explosives hazards test known as ESKIMO IV. (ESKIMO is an acronym for Explosive Safety Knowledge IMprovement Operation.) This was the fourth in a series of full-scale tests of earth-covered magazines sponsored by the DDESB. The main purpose of this test was to evaluate a new headwall and door combination by exposing it to explosive blast loading simulating that from detonation of the contents of another magazine filled with mass-detonating explosives at the minimum front-to-rear spacing now permitted by standards. This design had not been tested under these conditions.

ESKIMO I, the first test, was conducted in December 1971 to determine a safe, practicable minimum separation distance for face-on exposures of U.S. Army standard steel-arch magazines.[1] Explosion communication occurred to an acceptor igloo of this design at a distance in feet equal to $1.25 \times W^{1/3}$, in which W is the weight in pounds of the high explosive in storage, but failed to occur at a distance of $2.0 \times W^{1/3}$ to the rear of the donor. Further, the test revealed that safety and economy might be increased through improved design for closer balance in strength between the doors and headwall of the magazine. (A minimum separation distance in feet equal to $1.25 \times W^{1/3}$ in customary units is equal to approximately 0.5 in metric units, in which the separation distance is in meters and W is in kilograms.)

ESKIMO II was conducted in May 1973 to appraise magazine door and headwall designs.[2] A large, single-leaf sliding door withstood the blast with minor distortion, although the accompanying headwalls sustained severe damage. A Stradley-type headwall, on the other hand, incurred only minor damage. In addition, the noncircular (oval) steel arch tested with the Stradley headwall withstood the blast without breakup or severe distortion.

ESKIMO III was conducted in June 1974 to further extend the study of explosive-storage magazines, using information derived from ESKIMO I and II.[3] A further test of the oval arch and Stradley-type headwall, ESKIMO III used structures remaining from ESKIMO II, rebuilt as necessary, as well as new construction. Igloo B, the oval-arch magazine tested in ESKIMO II, was fitted with a newly designed Stradley-type headwall with a single-leaf, sliding door. ESKIMO II had proven that the Stradley-type headwall could withstand a face-on impulse of 1,750 psi-ms (12 066 kPa•ms) and that the steel oval-arch igloo could withstand the face-on impulses generated by that charge. ESKIMO III tested the ability of the new headwall to withstand the side-on blast imposed by the explosion of an adjacent magazine.

[1] Naval Weapons Center. *ESKIMO I Magazine Separation Test*, by Frederick H. Weals. China Lake, Calif., NWC, April 1973. 84 pp. (NWC TP 5430, publication UNCLASSIFIED.)

[2] Naval Weapons Center. *ESKIMO II Magazine Separation Test*, by Frederick H. Weals. China Lake, Calif., NWC, September 1974. 90 pp. (NWC TP 5557, publication UNCLASSIFIED.)

[3] Naval Weapons Center. *ESKIMO III Magazine Separation Test*, by Frederick H. Weals. China Lake, Calif., NWC, February 1976. 70 pp. (NWC TP 5771, publication UNCLASSIFIED.)

GENERAL DESCRIPTION

ESKIMO IV continued the study of explosive-storage magazines, using information from the prior tests in the ESKIMO series. The door and headwall combination used on the oval-arch magazine was again tested in ESKIMO IV but with face-on blast loading as compared with the side-on loading experienced with ESKIMO III. The door that had fallen off its supports in ESKIMO III was rehung in position. ESKIMO IV provided the initial test of the combination of a newly designed headwall and single-piece, sliding door under face-on loading. ESKIMO IV also included a rebuilt standard headwall and doors (OCE standard drawing 33-15-64) as a control structure, and a single-piece, sliding door, remaining from ESKIMO III, in combination with a rebuilt standard headwall.

This report discusses ESKIMO IV, its objectives, procedures, and results, and the conclusions drawn from these results.

TEST OBJECTIVES

The primary objective was to demonstrate the resistance of a newly designed headwall and door combination to blast simulating that possible at the minimum front-to-rear spacing now permitted for the semicircular and other standard earth-covered magazines. Other objectives were

1. Test of single-leaf, sliding door installed on a standard headwall (Igloo E) at a level of blast loading equal to that experienced by the newly designed headwall and door combination described above.

2. Acquisition of data on response of standard headwall and standard double-leaf, hinged door to blast loading from a hemispherical charge of TNT, the blast characteristics of which are well known.

TEST LAYOUT

TEST ARRAY

The ESKIMO IV test array consisted of three magazine structures each facing the explosion source 147 feet (45 meters) distant as shown in Figure 1. The construction of the various acceptor igloos is described in Table 1, and steel-arch construction is illustrated in Figure 2. Door construction for each igloo is described in Table 2, and door types are illustrated in Figure 3.

The primary target structure was the northeast magazine (Igloo B), consisting of a single-leaf, sliding door spanning a 10-foot (3-meter) horizontal opening and mounted on a modification of the headwall of a standard Stradley magazine. The headwall and door combination was designed for the ESKIMO series by Black & Veatch under the supervision of the Office, Chief of Engineers. The combination was built prior to ESKIMO III (a test of the noncircular arch under lateral explosive loading) and was only slightly damaged in that test.

The front of the east magazine (Igloo D) was rebuilt as before with the headwall and the two-leaf, hinged, steel-plate door of the standard circular steel-arch magazine. Exposed to the same level of loading as the primary, it served as a control structure to demonstrate directly the relative strength of the primary target.

The west magazine (Igloo E) was also rebuilt with the headwall of the standard circular steel-arch magazine, but fitted with a single-leaf, sliding door remaining from ESKIMO III and only slightly damaged in that test. This combination was tested inconclusively in ESKIMO II, but the response to overload in that test indicated a serious imbalance in strength between the door and the headwall. In a related (front-to-side) exposure in ESKIMO III, instrument records gave no direct measure of impulse load, and the light damage observed suggested a possible undertest in that case due to shielding by other structures.

The ESKIMO IV test utilized a nearly ideal explosion source to generate blast loading. It afforded the opportunity for more extensive source diagnostics and dynamic response measurements on the target structures than did previous tests of the ESKIMO series. As in ESKIMO III, token explosive charges were not used as indicators of explosion communication; instead, more detailed response measurements and damage observations were substituted for this purpose.

EXPLOSION SOURCE

The donor charge consisted of approximately 37,000 pounds (16 783 kilograms) of TNT explosive contained in a hemisphere built of 8-pound (3.6-kilogram) blocks that were detonated by means of an initiation system located at the center of the base of the hemisphere. To ensure that the proper number of TNT blocks were placed in the stack to provide a total closely approximating 37,000 pounds (16 783 kilograms), the individual blocks in six randomly selected boxes were weighed. Each box contained eight TNT blocks. Of the 48 blocks weighed, the lightest was 7.71 pounds (3.497 kilograms) and the heaviest was 8.53 pounds (3.869 kilograms). The average TNT weight per block was 8.029 pounds (3.642 kilograms). All values represent net TNT weight, the weight of the paper being deducted.

The explosive stacking plan called for 4,625 rectangular blocks of TNT. Four blocks at the center of the base of the hemisphere were replaced with a booster of plastic explosive C-4. Thus, a total of 4,621 blocks of TNT were stacked in the shape of a solid, stable hemisphere in accordance with the pattern provided by DDESB and as illustrated by Figures 4, 5, 6, and 7. Demolition blocks M034 were furnished by the sponsor from U.S. Army sources at Letterkenny Army Depot, Chambersburg, Pa.

An explosive detonator and booster system was provided to ensure safe, reliable initiation at the center of the charge. The donor stack was primed with C-4 booster imbedded with four Primacord leads with percussion caps (Figure 8).

The source size was such as to duplicate the free-field peak pressure and impulse observed at a scaled distance of 2.0 ft/lb$^{1/3}$ to the rear of the donor magazine in ESKIMO III, which contained 750-pound (340-kilogram) bombs filled with a total of 350,000 pounds (158 757 kilograms) of Tritonal. The previously observed values of peak pressure and impulse were in the ranges of 50 to 55 psi (344 to 379 kilopascals) and 550 to 600 psi-ms (3790 to 4137 kPa•ms), respectively. It can be shown that these levels would be produced by a 37,000-pound (16 783-kilogram) TNT hemisphere centered 147 feet (45 meters) away, a position coinciding with the center of the explosion source in ESKIMO II. This coincidence permitted the economical reuse of assets remaining from ESKIMO III for control and comparison purposes in support of the primary objective of the proposed test.

INSTRUMENTATION

Blast

On each target magazine headwall, pressure gauges were mounted flush with the surface at positions shown in Figures 9 and 10. Necessary signal processing and recording equipment was provided.

Three air-pressure gauges were provided in the unobstructed sector of the igloo complex. Two gauges were set atop the earth fill of Igloo B (Figure 11).

Four earth-pressure gauges were installed in one concrete thrust beam of Igloo B (Figure 11). These consisted of load cells measuring the force impinging on a circular steel plate 1-inch thick and 8 inches in diameter.

Ballistic Research Laboratories (BRL) self-recording gauges for pressure measurement in three directions in the far field, as shown in Figure 12, were installed.

Table 3 shows blast gauge instrumentation with anticipated overpressures.

Structure Response

Linear displacement transducers and single-axis accelerometers for measurement of dynamic structure response time histories were installed at locations on the target headwalls shown in Figures 13 and 14. Table 4 lists the accelerometer locations and the anticipated accelerations.

Prior to the test, survey monuments and benchmarks were used to define reference planes and to obtain initial headwall and floor positions for permanent deformation measurements afterward.

Photography

Motion picture coverage of the fireball was provided as described in Table 5 to detect anomalies should any occur in the directions of the blast gauge lines.

Timing

Timing was provided on records of near-field air-pressure gauges, earth-pressure gauges, accelerometers, linear-motion tranducers, and strain gauges so that the events recorded were correlatable.

Zero Time Indicator

Zero time or time of detonation of the explosive hemisphere was determined by two ionization probes that were placed in the donor stack to generate a zero time pulse.

TEST RESULTS

GENERAL

The data recorded by the BRL gauges are summarized in Table 6 and are plotted in Figures 15 through 20.

A summary of electronic-blast and air-pressure gauge data is given in Table 7. Data plots for the blast gauges are shown in Figures 21 through 24.

Table 8 lists accelerometer data recorded on the headwall in Igloo B only. The data are plotted in Figures 25 and 26.

Earth-pressure gauge data are given in Table 9 and are plotted in Figure 27.

Linear-motion data recorded along various parts of the igloos are listed in Table 10 and displayed in Figures 28 through 30.

The overpressures from records of blast gauges placed at ground level that are presented in Figures 15 through 24 are compared with a standard curve for hemispherical stacks of TNT in Figure 31. The generally close agreement of overpressure values from this test with standard values shows that complete or near-complete detonation of the explosive stack was achieved. The comparison of all gauges at comparable positions and distances from the center of the explosive source shows blast symmetry.

Figure 32 is an aerial view showing post-test conditions including the crater east of the explosive stack and darkening of the ground surface near the site of the explosion. No explanation is offered for the nonsymmetrical distribution of the darkened area. Figure 32 also shows several ponds of water, the most notable being directly east of the crater.

OBSERVED STRUCTURAL RESPONSE

Igloo B (Northeast)

The headwall incurred minor damage and experienced some permanent movement, most of which was around and above the door opening. Cracking and spalling of concrete was minor and represented no threat to usual magazine storage. The door was permanently deformed by the blast but remained standing at the door opening. The deformation was greatest near the bottom where the bow at the center approximated 13 inches (330 millimeters) as measured from a straight line connecting door edges and at a position midway between the horizontally spanning interior wide flange structural members. Figures 33 through 39 are post-test views of Igloo B. Figure 40 indicates headwall movement, and Figure 41 shows post-test static measurements on the door of Igloo B.

Igloo D (East)

This igloo was used as a control structure. Headwalls and doors of this type have been used in all ESKIMO tests and provide one means of comparison from test to test. The doors of Igloo D

failed in a fashion previously experienced with this design by moving through the doorway opening and into the magazine interior. The door hinges on the right and left sides were sheared off.

Concrete cracking and spalling and permanent headwall deformation were greater than that of Igloo B but considerably less than that of Igloo E.

Figures 42 through 44 show post-test damage, and Figure 45 depicts headwall movement in Igloo D.

Igloo E (West)

As in prior tests combining the single-leaf, horizontally spanning, sliding door with the standard reinforced concrete headwall (per OCE standard drawing 33-15-64), results showed an imbalance in strength between the door and the wall. The door retained its basic integrity despite deformation, but the headwall suffered substantial damage. In effect, the door intercepted the blast load and transmitted it to the headwall. The early failure of doors on the east igloo (Igloo D) resulted in relatively less door load being transmitted to the headwalls of this structure.

Damage to Igloo E is shown in Figures 46 through 50. Figure 51 shows headwall movement in Igloo E.

CONCLUSIONS

The blast produced by the donor stack of explosives was essentially as predicted and properly simulated conditions at a scaled distance of 2.0 ft/lb$^{1/3}$ to the rear of the donor magazine in ESKIMO III, which contained 750-pound (340-kilogram) bombs filled [illegible] a total of 350,000 pounds (158 757 kilograms) of Tritonal.

Structural response of the headwall and door combination used on the northeast igloo (Igloo B) was well within acceptable limits, and this combination is considered adequate to protect all magazine stores against propagation of explosion under the conditions simulated and blast effects produced in the test. The response of the east control igloo (Igloo D) was essentially as expected with door failure creating a hazard to more sensitive types of explosive stores that could prove unacceptable. Fragment velocities based on position, character, linear-motion instrumentation, and comparison with prior tests were judged acceptable.

The response of the west magazine (Igloo E) showed significant damage to the reinforced concrete headwall and marked imbalance in strength between the one-piece, horizontally spanning door and the concrete headwall. No direct attempt was made to measure concrete fragment velocities. Based on wall velocities recorded by linear-motion transducers and the position and character of fragments found inside the magazine, it is considered that fragment velocities produced only a marginal hazard to sensitive types of materials and no significant hazard to many types of stores.

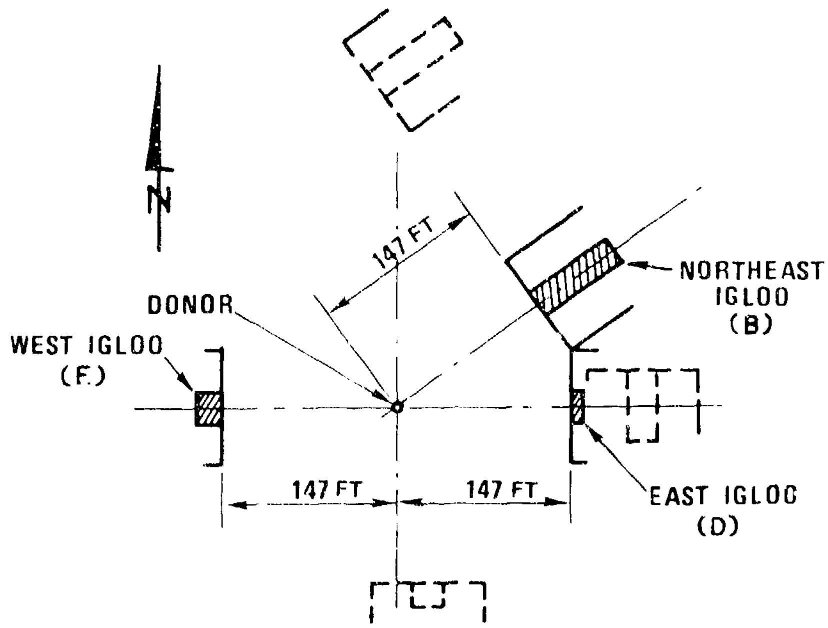


FIGURE 1. ESKIMO IV Test Area Layout (1 foot = 0.305 meter).

TABLE 1. Igloo Construction.

Igloo	Position relative to donor	Length		Steel arch, floor, rear wall, wing walls, and earth cover	Headwall type	Headwall drawing
		ft	m			
B	Northeast	80	24	Noncircular steel arch design approximates size and shape of Stradley igloo	Redesigned Stradley type	Black & Veatch
D	East	10	3	All new construction, design same as ESKIMO I, II, and III	Same as ESKIMO I, II, and III	OCE std dwg 33-15-64
F	West	20	6	Remaining from ESKIMO III	Same as ESKIMO I, II, and III except for door modifications	OCE std dwg 33-15-64

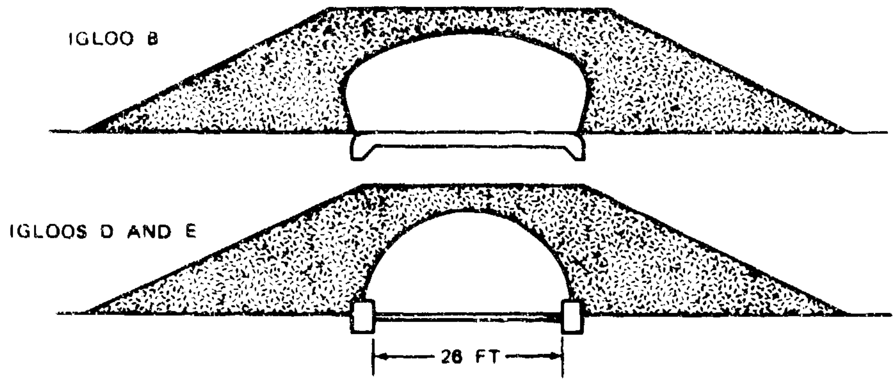


FIGURE 2. Cross Sections of Steel-Arch Construction for Igloos of ESKIMO IV. (1 foot = 0.305 meter.)

TABLE 2. Door Construction.

Door height and width in each case was 10 feet (3.05 meters).

Igloo	Door type	Door drawing
B	Single leaf, sliding	Black & Veatch unnumbered dwg., 25 Oct 1972
D	Double leaf, hinged	OCE std. dwg. 33-15-64
E	Single leaf, sliding	Black & Veatch unnumbered dwg., 25 Oct 1972

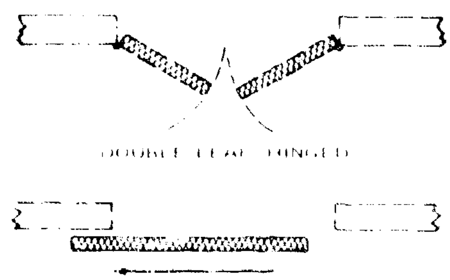


FIGURE 3. Types of Doors Used on ESKIMO IV Igloos.

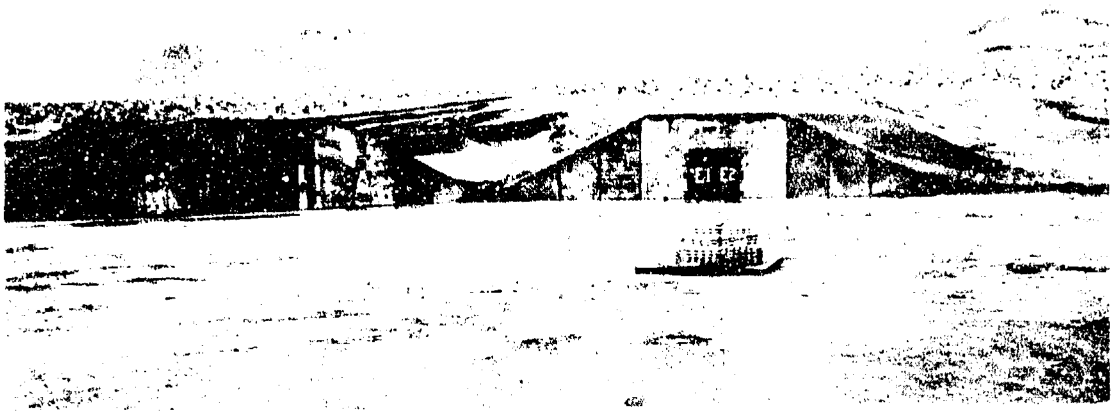


FIGURE 4. View of Test Site Showing Explosive Charge and Igloos B (Left) and D.

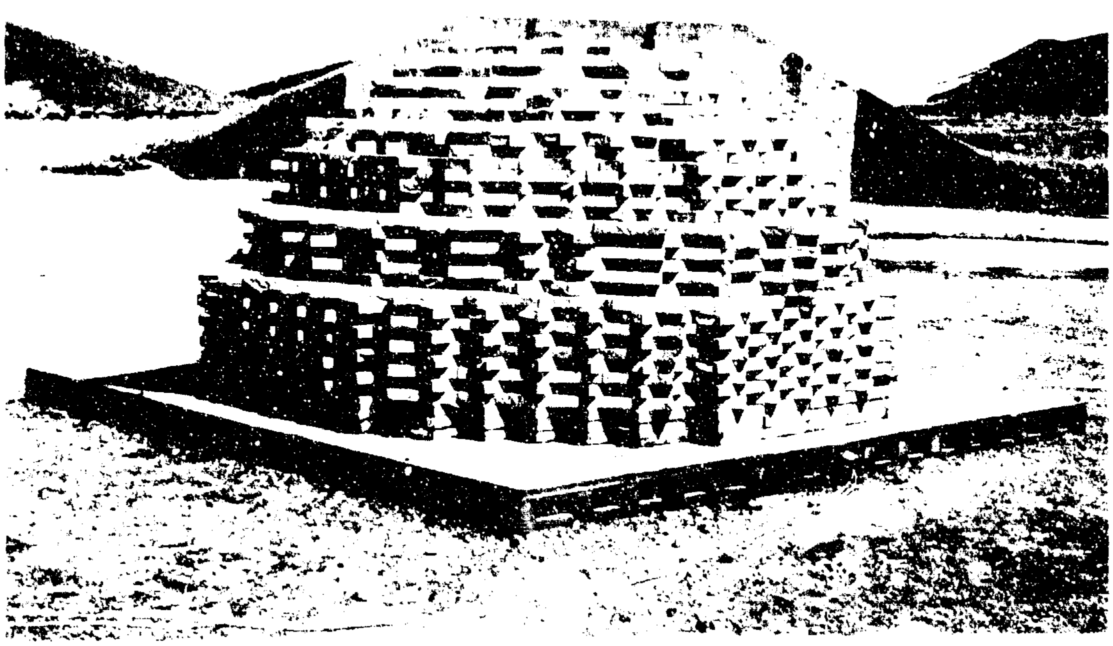


FIGURE 5. Close-up View of Explosive Charge With Igloo B in Background.

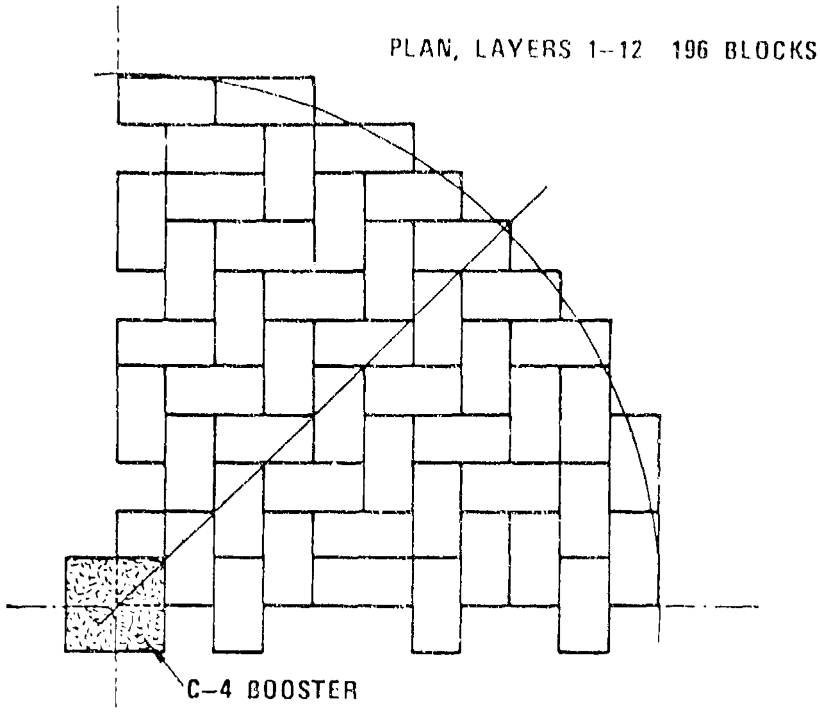


FIGURE 6. Horizontal Section of One Quadrant of TNT Donor Stack.

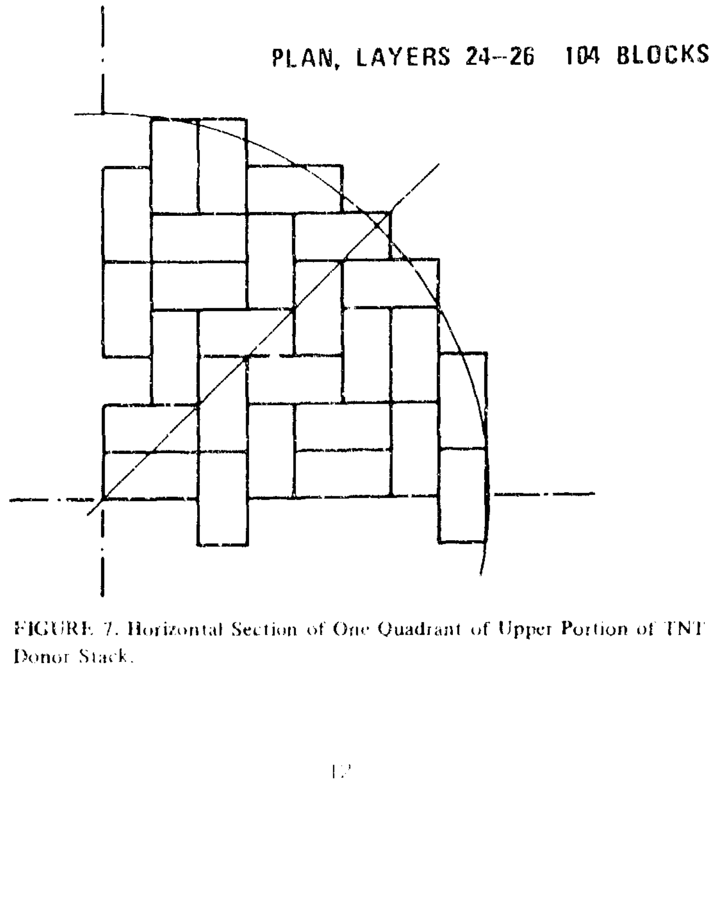


FIGURE 7. Horizontal Section of One Quadrant of Upper Portion of TNT Donor Stack.

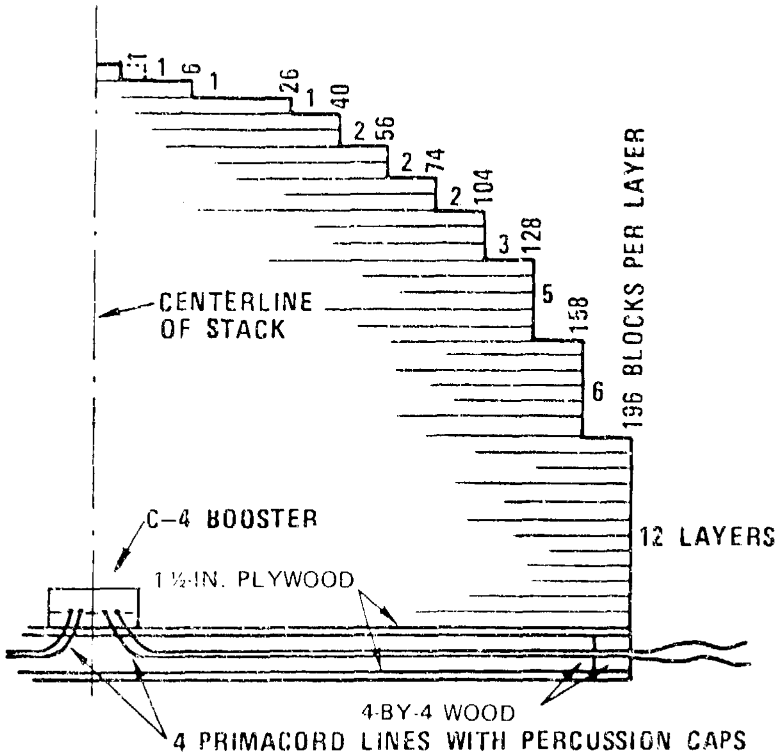
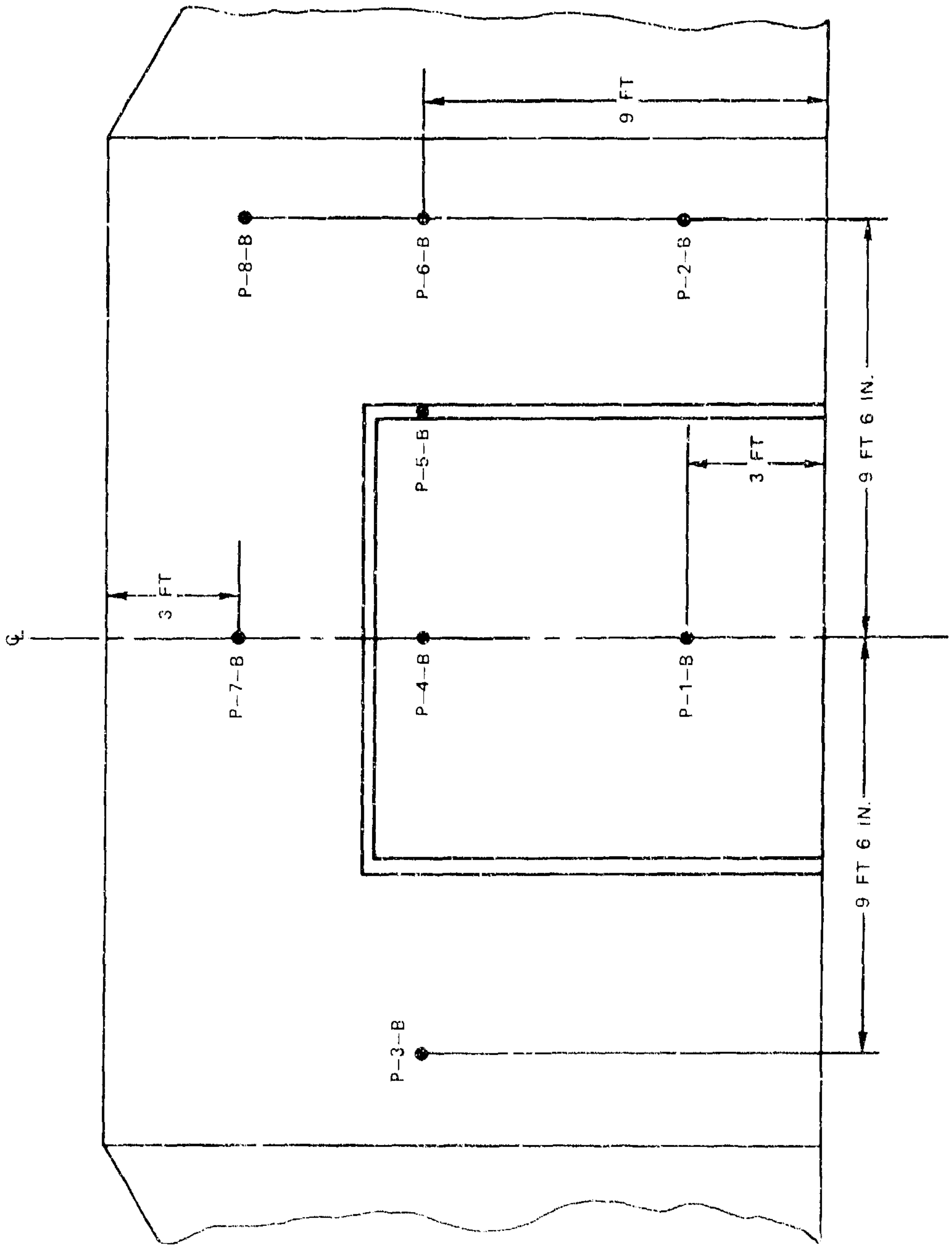


FIGURE 8. Vertical Section of One-Half of TNT Donor Stack. (1 inch = 25.4 millimeters.)



● PRESSURE GAUGE

FIGURE 9. Placement of Pressure Gauges on Headwall of Igloo B in ESKIMO IV. (1 foot = 0.305 meter.)

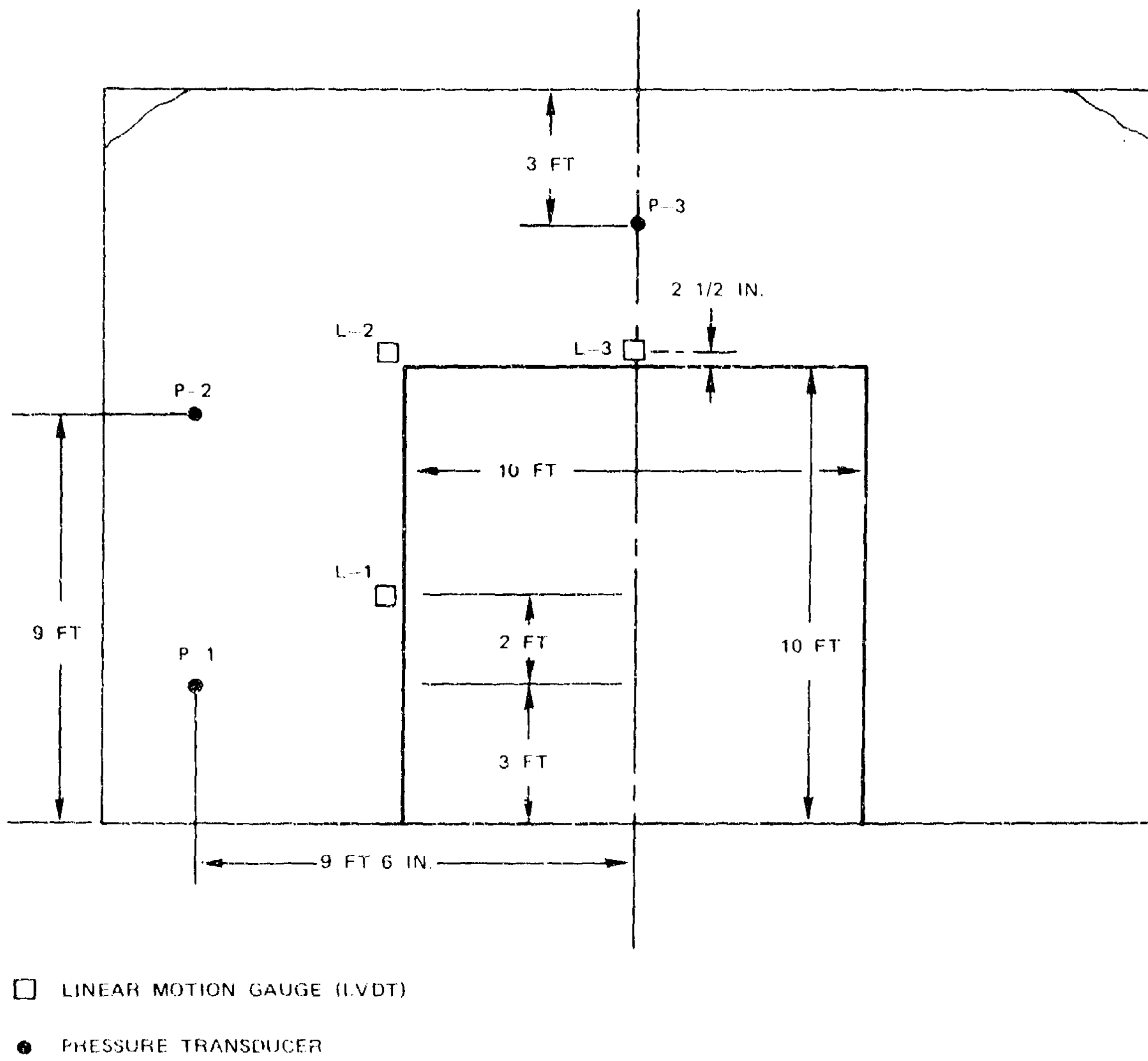


FIGURE 10. Placement of Transducers on Headwalls of Igloos D and E in ESKIMO IV. (1 foot = 0.305 meter.)

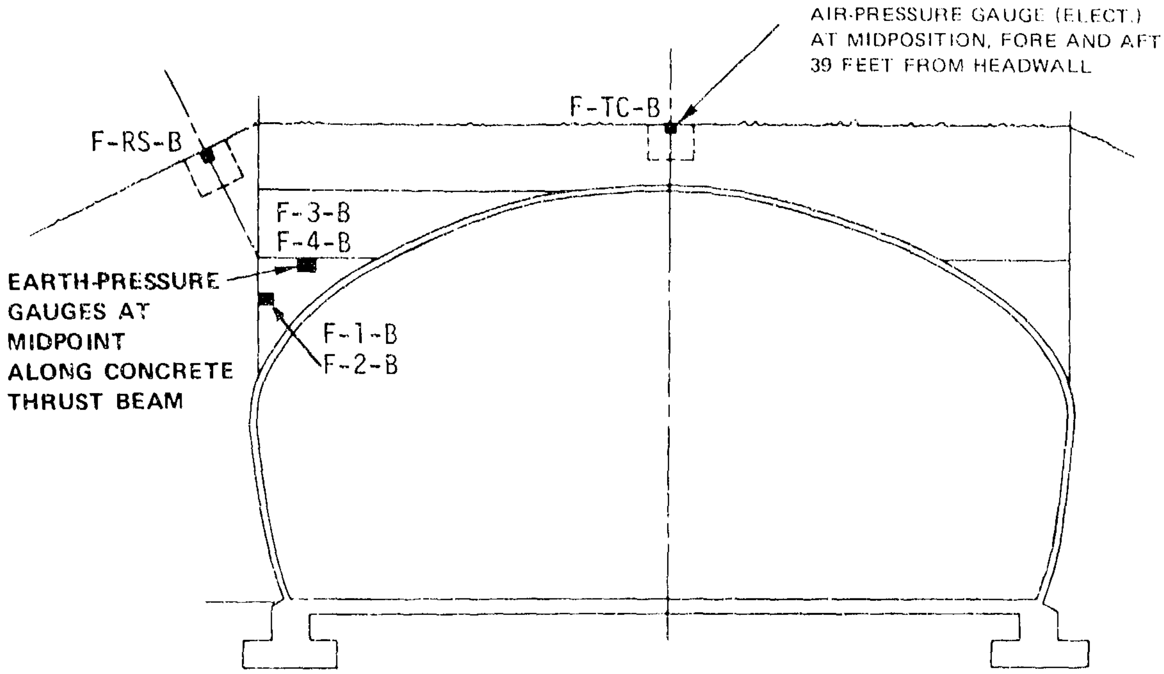


FIGURE 11. Placement of Air- and Earth-Pressure Gauges on or Under Earth Fill of Stradley-Type Igloo B. (1 foot = 0.305 meter.)

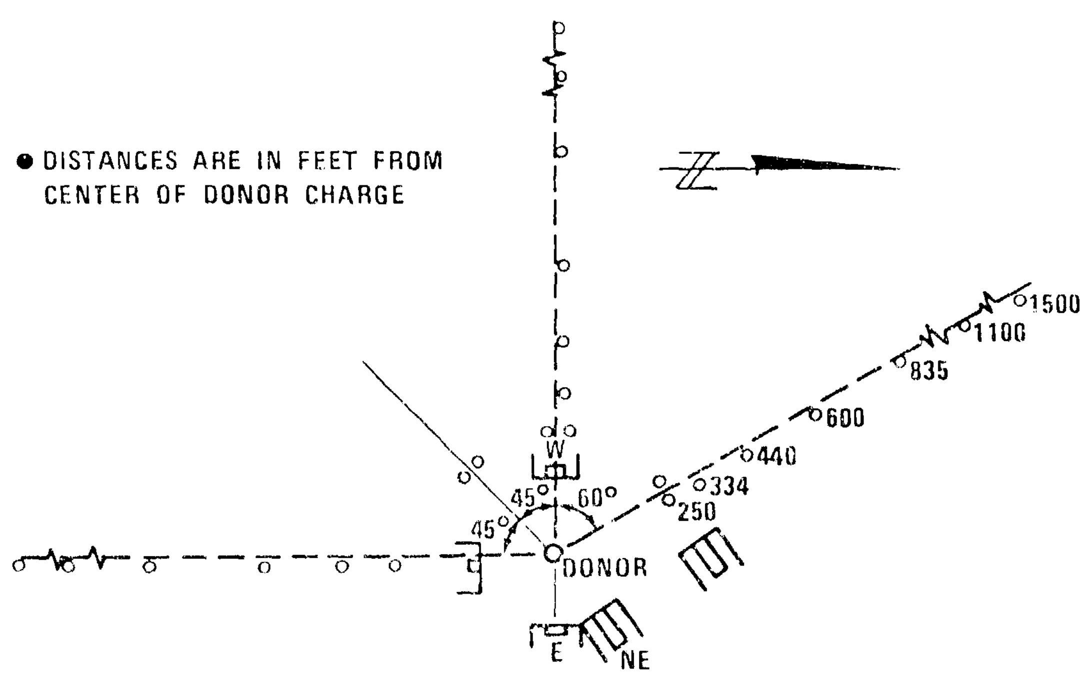


FIGURE 12. BRL Gauge Locations. (1 foot = 0.305 meter.)

TABLE 3. Schedule of Gauges for Measurement of Air Blast.

Piezoelectric or Strain-Gauge Type

Gauge position	Distance from center of explosive donor		Estimated peak overpressure		Calibrate to overpressure	
	ft	m	psi	kPa	psi	kPa
Mounted on igloo headwalls	147	45	215	1482	400	2758
Ground level, northwest of donor ..	134	41	65	448	120	827
	147	45	52	359	100	689
	167	51	41	283	80	552
In earth fill over Igloo B	187	57	32	221	60	414

BRL Self-Recording Gauges

Radial distance from donor		$D/W^{1/3}$	Number of gauges			Estimated maximum peak overpressure		Capsule rating	
ft	m		NW leg	W leg	S leg	psi	kPa	psi	kPa
250	76	7.5	2	2	2[a]	17.0	117	25	172
334	102	10.0	2	2	2	10.0	69	15	103
440	134	13.5	2	2	2	5.5	38	15	103
600	183	18.0	2	2	2	3.6	25	5	34
835	255	25.0	2	2	2	2.3	16	5	34
1,100	335	33.0	2	2	2	1.5	10	5	34
1,500	457	45.0	2	2	2	1.0	7	1	7

[a] 250-ft (76-m) position is on southwest leg in lieu of south.

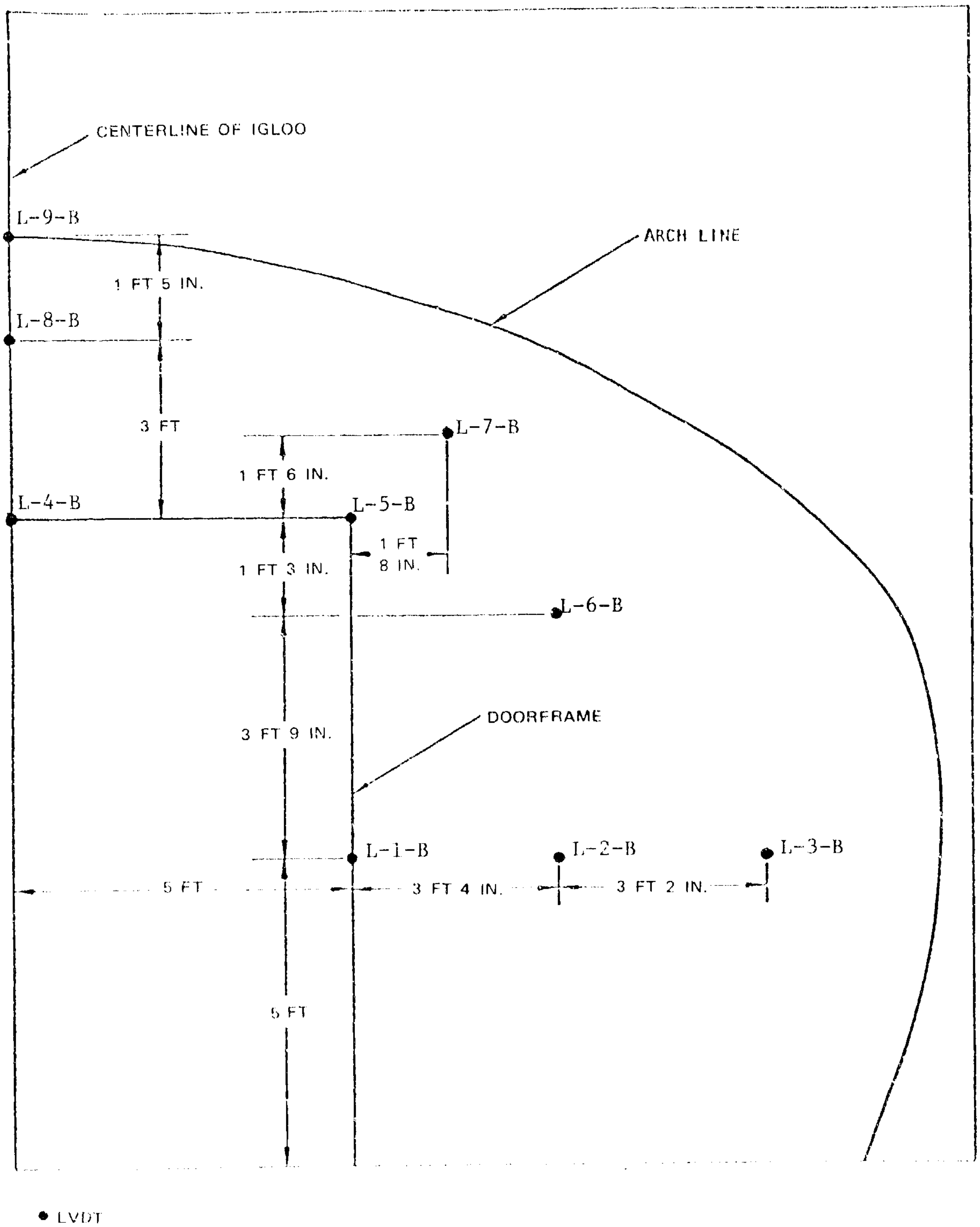


FIGURE 13. Placement of LVDT Transducers on Igloo B Headwall in ESKIMO IV. (1 foot = 0.305 meter.)

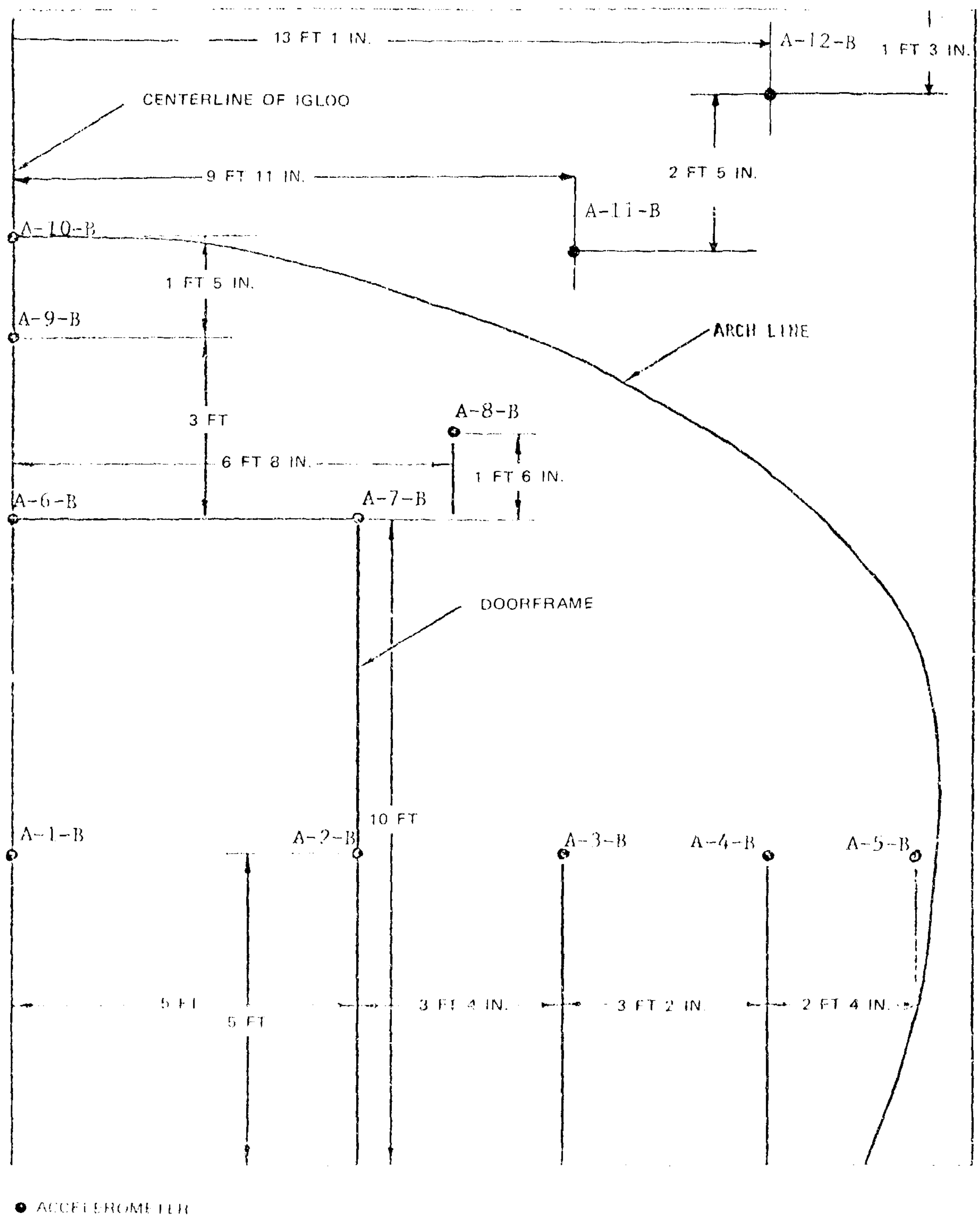


FIGURE 14. Placement of Accelerometers on Igloo B Headwall in ESKIMO IV. (1 foot = 0.305 meter.)

TABLE 4. Schedule of Accelerometers.

Position	Estimated max. acceleration, g	Accelerometer rating, g
Door	630	1,000
Headwall, away from door	150	300
Headwall, near door	200	300

TABLE 5. Camera Schedules.

Position identification	Approximate distance		Camera	Coverage	Field of view width		Frames per second
	ft	m			ft	m	
South or west	1,500	457	35 mm	General site area, donor and igloos	400	122	120
South	1,500	457	16 mm	General site area, donor and igloos	400	122	1,000
South	1,500	457	16 mm	Donor and Igloos B and D	160	49	4,000
West (in instrumentation barricade)	950	290	16 mm	Center on igloos	400	122	4,000
On hill west-southwest of ground zero	1,500	457	16 mm	View of donor and Igloos B and D	400	122	400

TABLE 6. Summary of BRL Gauge Data.

Position identification	Distance		Maximum overpressure		Impulse		Duration, ms
	ft	m	psi	kPa	psi·ms	kPa·ms	
1NW	250	76	18.0521	124.46	332.78	2294.44	78.15
1NW	250	76	15.2425	105.09	238.09	1641.57	57.87
2NW	334	102	9.4982	65.49	78.08	538.34	22.45
3NW	440	134	8.0820	55.72	223.76	1542.77	105.56
4NW	600	183	3.7224	25.67	141.00	972.16	101.08
5NW	835	255	2.4129	16.64	123.43	851.02	132.19
6NW	1,100	335	1.6272	11.22	91.99	634.25	137.21
7NW	1,500	457	1.1300	7.79	...[a]	...	...[a]
1W	250	76	17.6296	121.55	315.39	2174.55	55.93
1W	250	76	16.7588	115.55	268.15	1848.83	49.31
2W	334	102	10.1020	69.65	254.19	1752.58	99.75
3W	440	134	6.4869	44.73	145.97	1006.43	67.34
4W	600	183	3.8944	26.85	156.81	1081.17	116.59
5W	835	255	2.2409	15.45	109.57	755.46	117.64
6W	1,100	335	1.7614	12.14	69.18	476.98	99.23
7W	1,500	457	1.8289	12.61	...[b]	...	...[b]
1S	250	76	18.7075	128.98	...	...	...
1S	250	76	18.1589	125.20	433.29	2987.43	74.13
2S	334	102	11.6340	80.21	238.19	164.23	70.19
3S	440	134	5.8732	40.49	187.91	1295.59	85.57
4S	600	183	3.5735	24.64	147.04	1013.81	98.08
5S	835	255	2.3121	15.94	115.12	793.72	118.76
6S	1,100	335	1.5392	10.61	91.32	629.63	131.52
7S	1,500	457	1.5208	10.49	105.28	725.88	149.55

[a] Unreliable data, see Figure 16.

[b] Unreliable data, see Figure 18.

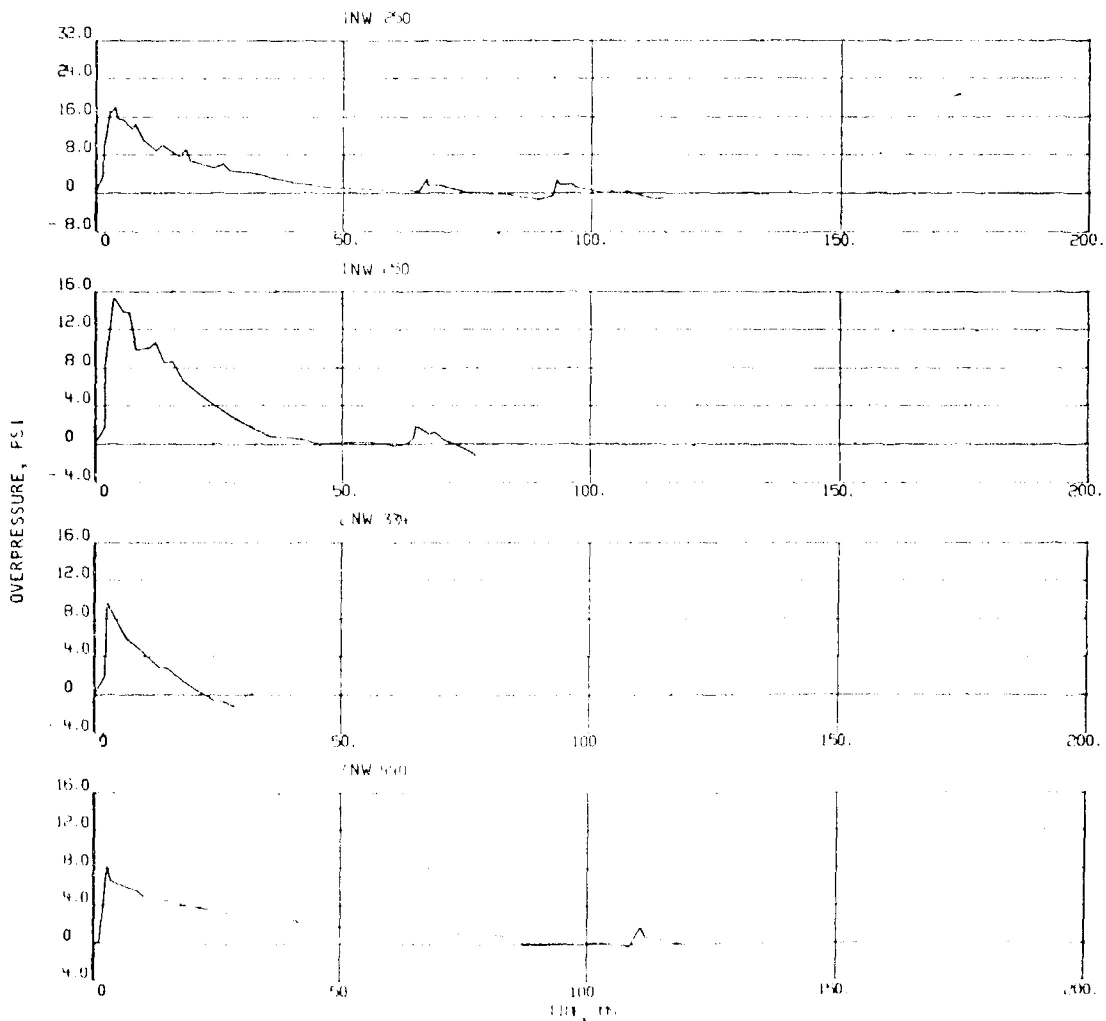


FIGURE 15. Data Plots for BRL Gauges 1 Through 3 on Northwest Leg. The numbers above the plots refer to the distance in feet from the donor. Data plots from gauges that registered only the maximum overpressure have been omitted from this series. (The metric equivalents for these plotted data are given in Table 6.)

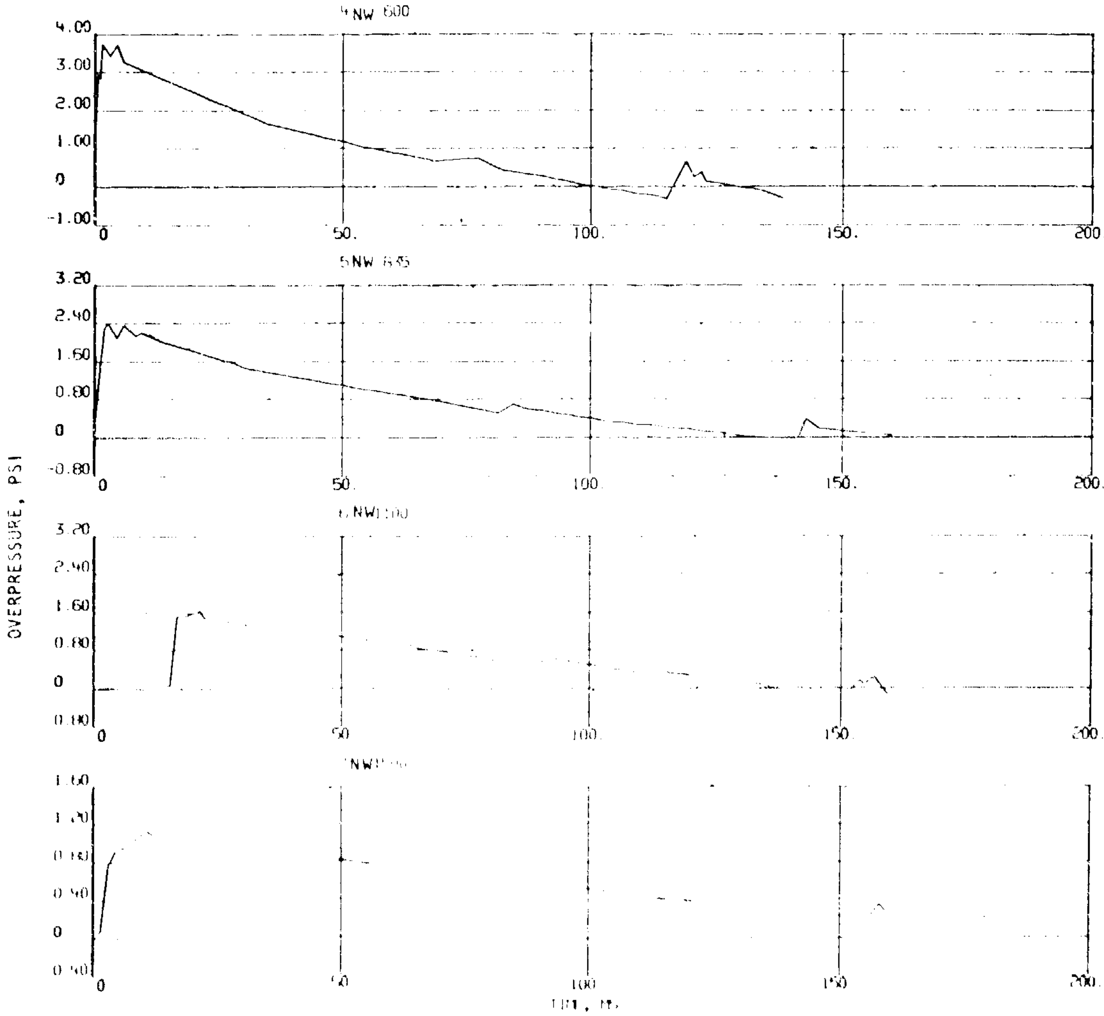


FIGURE 16. Data Plots for BRL Gauges 4 Through 7 on Northwest Leg. (The metric equivalents for these plotted data are given in Table 6.)

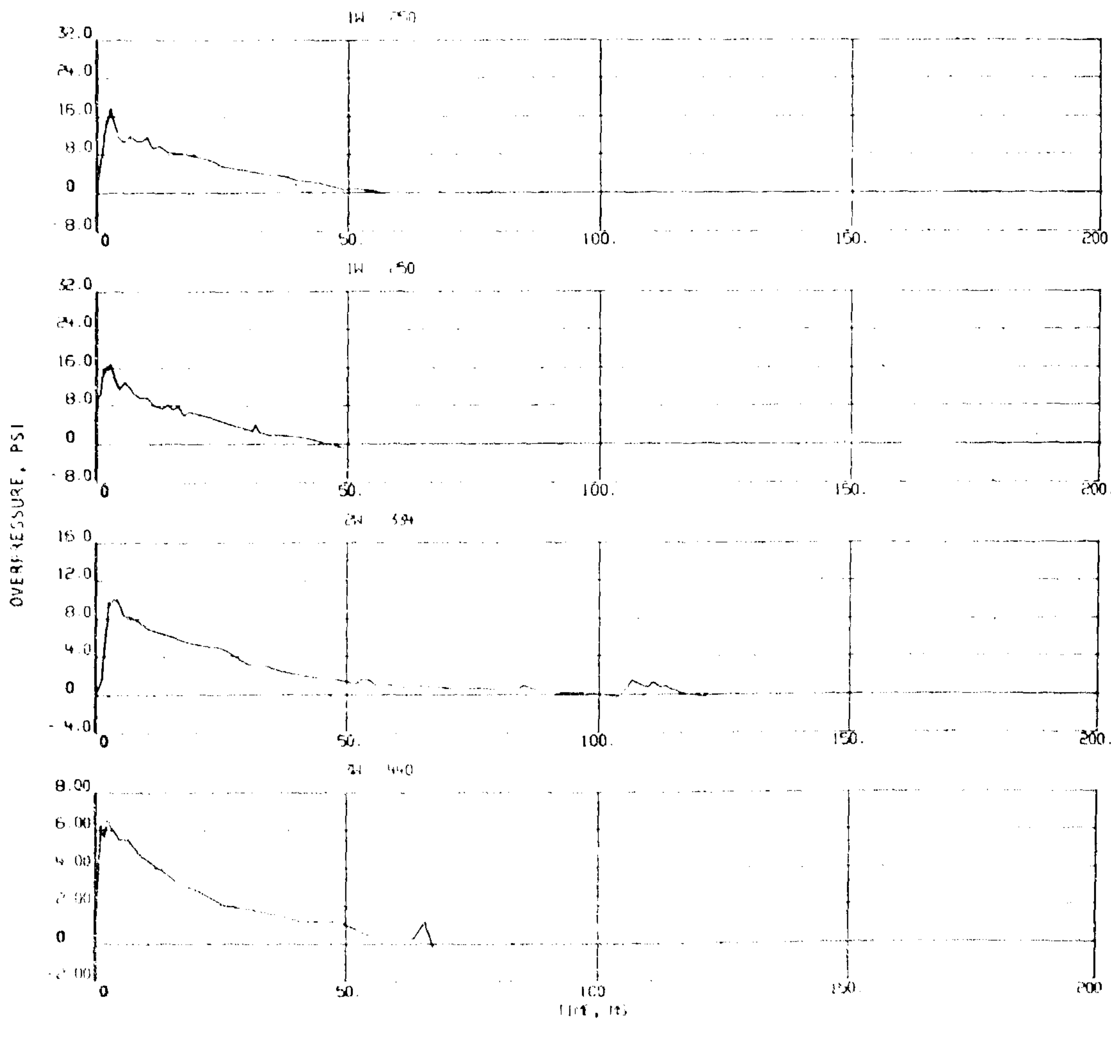


FIGURE 12. Data Plots for BRL Gauges 1 Through 3 on West Leg. (The metric equivalents for these plotted data are given in Table 6.)

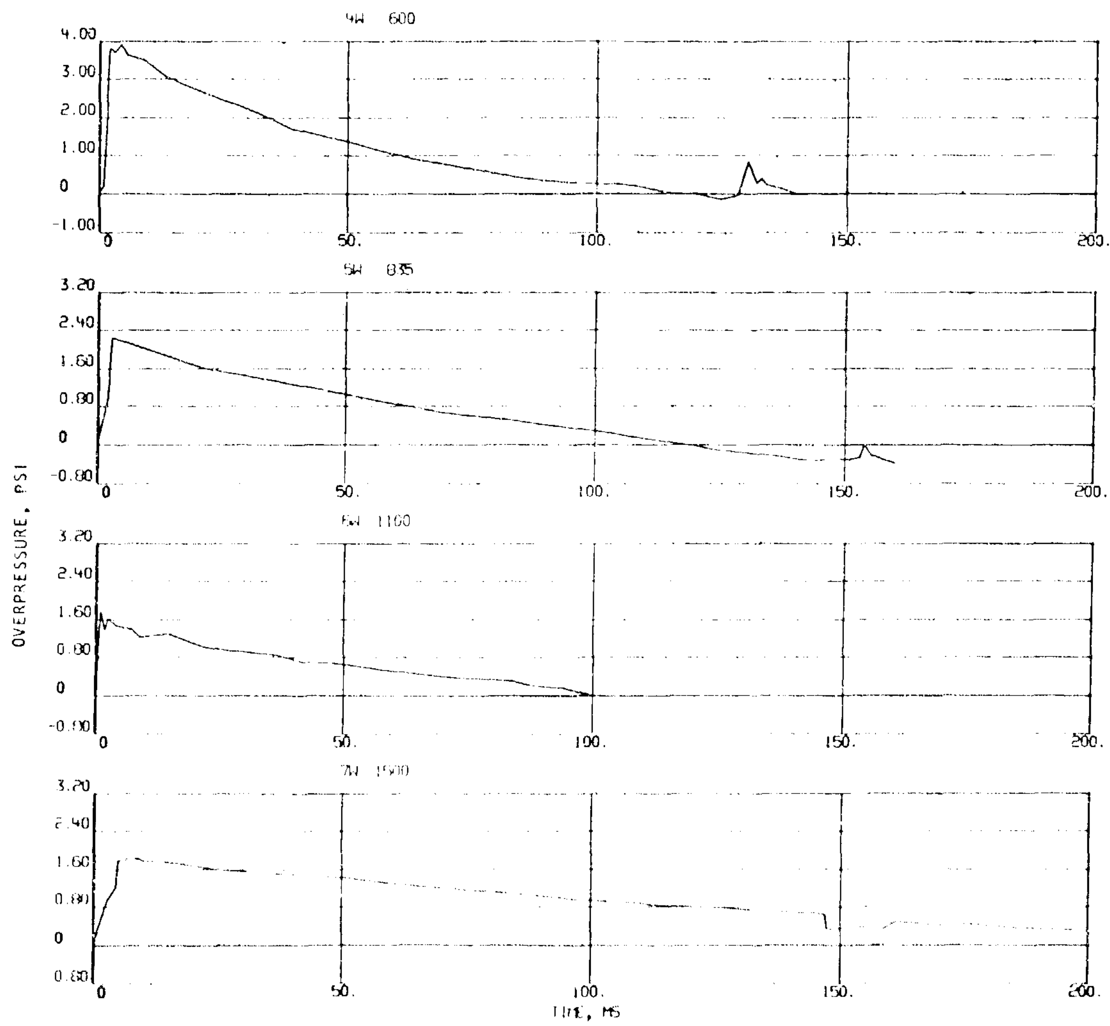


FIGURE 18. Data Plots for BRL Gauges 4 Through 7 on West Leg. (The metric equivalents for these plotted data are given in Table 6.)

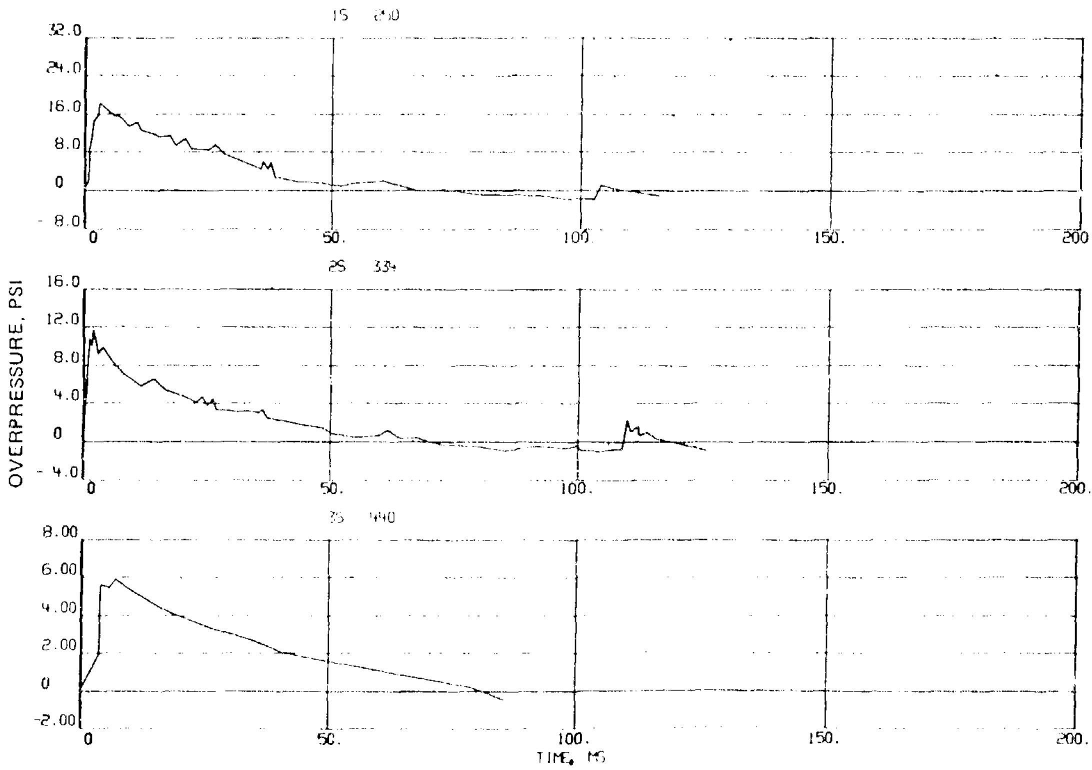


FIGURE 19. Data Plots for BRL Gauges 1 Through 3 on South Leg. (The metric equivalents for these plotted data are given in Table 6.)

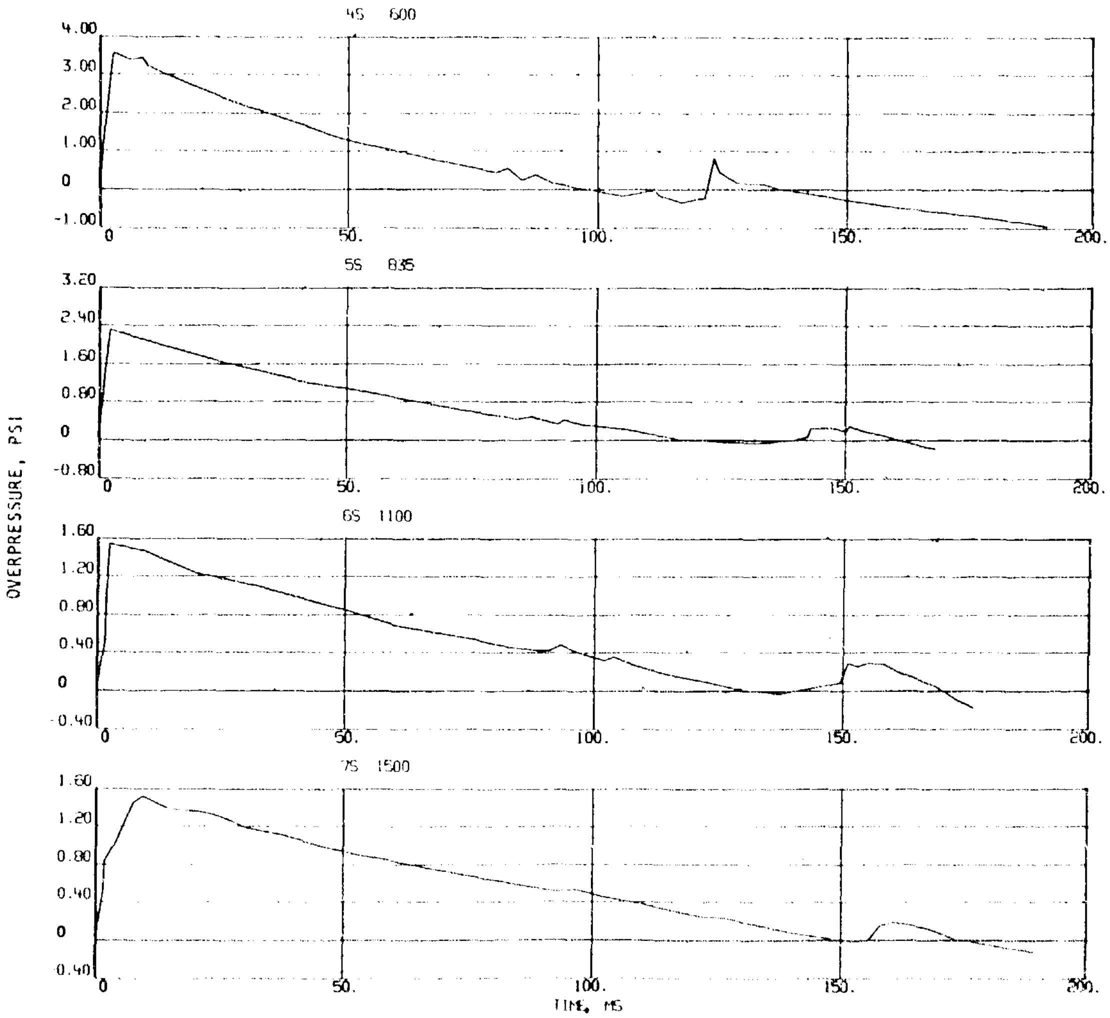


FIGURE 20. Data Plots for BRL Gauges 4 Through 7 on South Leg. (The metric equivalents for these plotted data are given in Table 6.)

TABLE 7. Summary of Electronic-Blast and Air-Pressure Gauge Data.

Position identification	Distance		Maximum overpressure		Impulse		Duration, ms
	ft	m	psi	kPa	psi-ms	kPa·ms	
P-1-B	147	45	202.4528	1395.86	1082.14	7461.09	22.94
P-2-B	147	45	215.1632	1483.49	1157.51	7980.75	13.33
P-3-B	147	45	235.5903	1624.33	1055.18	7275.20	12.10
P-4-B	147	45	. . .[a]	. . .[a]	. . .[a]	. . .	. . .[a]
P-5-B	147	45	176.9481	1220.01	978.66	6747.62	17.95
P-6-B	147	45	290.5473	2003.25	1191.65	8216.13	14.32
P-7-B	147	45	241.3210	1663.84	948.48	6539.53	12.41
P-8-B	147	45	208.6601	1438.66	992.72	6844.56	13.44
P-1-D	147	45	213.6456	1473.03	1075.20	7413.24	17.78
P-2-D	147	45	229.5419	1582.63	1056.28	7282.79	16.12
P-3-D	147	45	276.4415	1905.99	858.56[b]	5919.56	8.61[b]
P-2-E	147	45	273.5294	1885.91	1444.30	9962.23	15.48
P-3-E	147	45	241.9643	1668.28	1045.13	7205.91	15.56
P-134	134	41	87.9491	606.38	616.43	4250.13	42.94
P-147	147	45	64.1722	442.45	475.07	3275.49	25.90
P-167	167	51	43.2850	298.43	432.41	2981.36	34.22
F-RS-B	187	57	33.4	230.28	416.0	2868.22	37.8
F-TC-B	187	[illegible]	37.2	256.48	410.3	2828.92	34.7

NOTE: P-1-B through P-8-B: on wall of Igloo B.
P-1-D through P-3-D: on wall of Igloo D.
P-2-E and P-3-E: on wall of Igloo E.
P-134, P-147, and P-167: at ground level at 134, 147, and 167 feet, respectively, northwest of donor center.
F-RS-B and F-TC-B: air-pressure gauges in earth fill in Igloo B.

[a] Poor record.

[b] Based on incomplete trace. Extrapolation to zero overpressure would result in higher values.

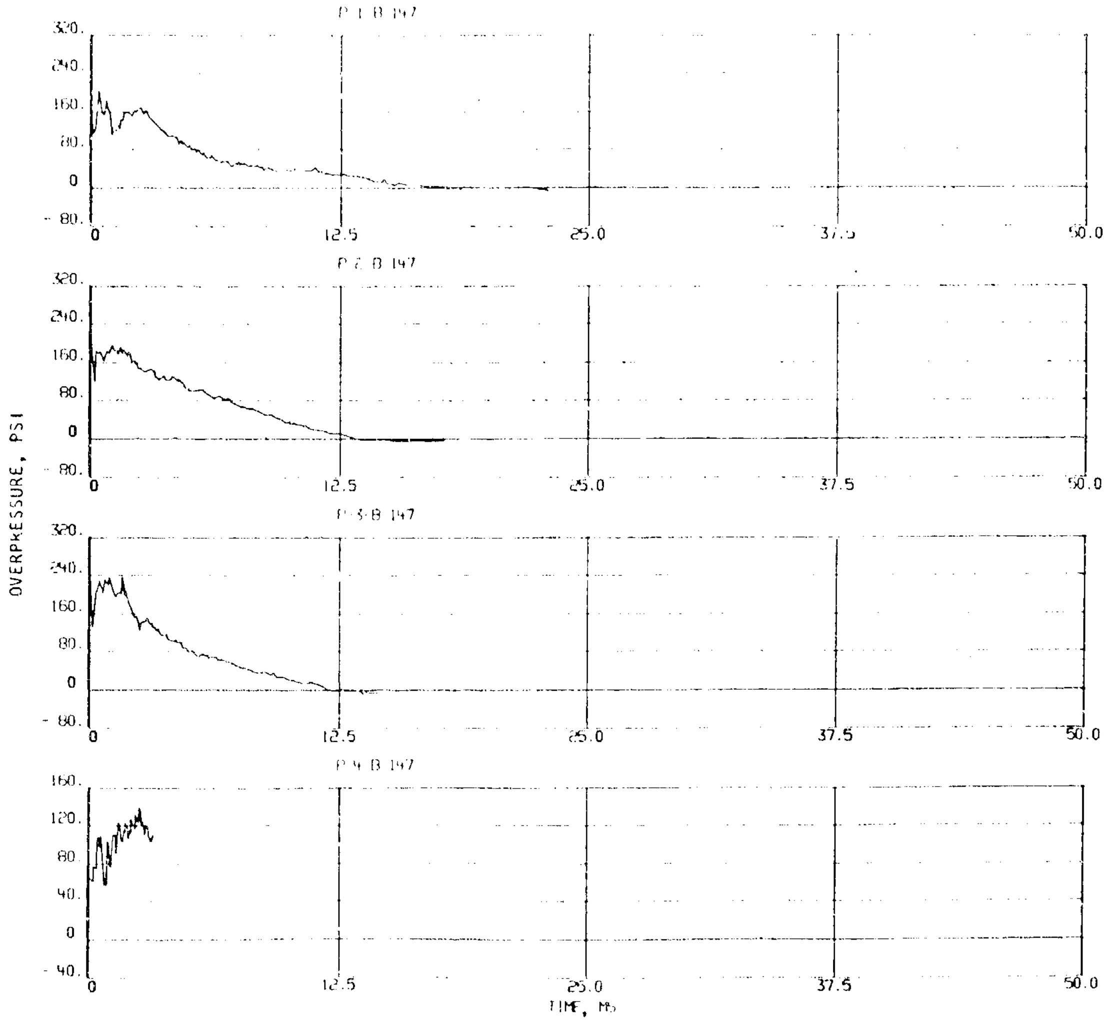


FIGURE 21. Data Plots for Electronic Blast Gauges P-1-B Through P-4-B Located on Headwall of Igloo B. (The metric equivalents for these plotted data are given in Table 7.)

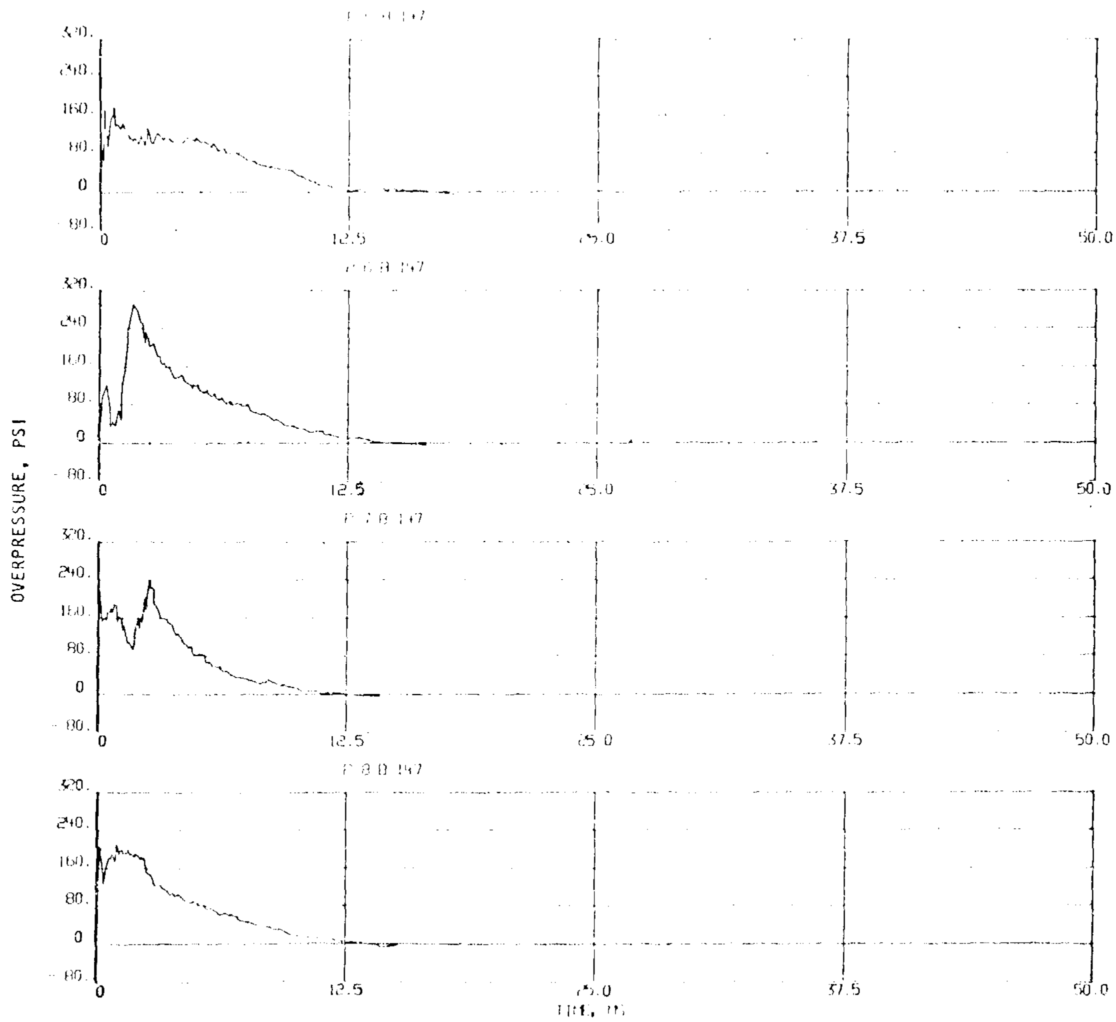


FIGURE 22. Data Plots for Electronic Blast Gauges P-5-B Through P-8-B Located on Headwall of Igloo B. (The metric equivalents for these plotted data are given in Table 7.)

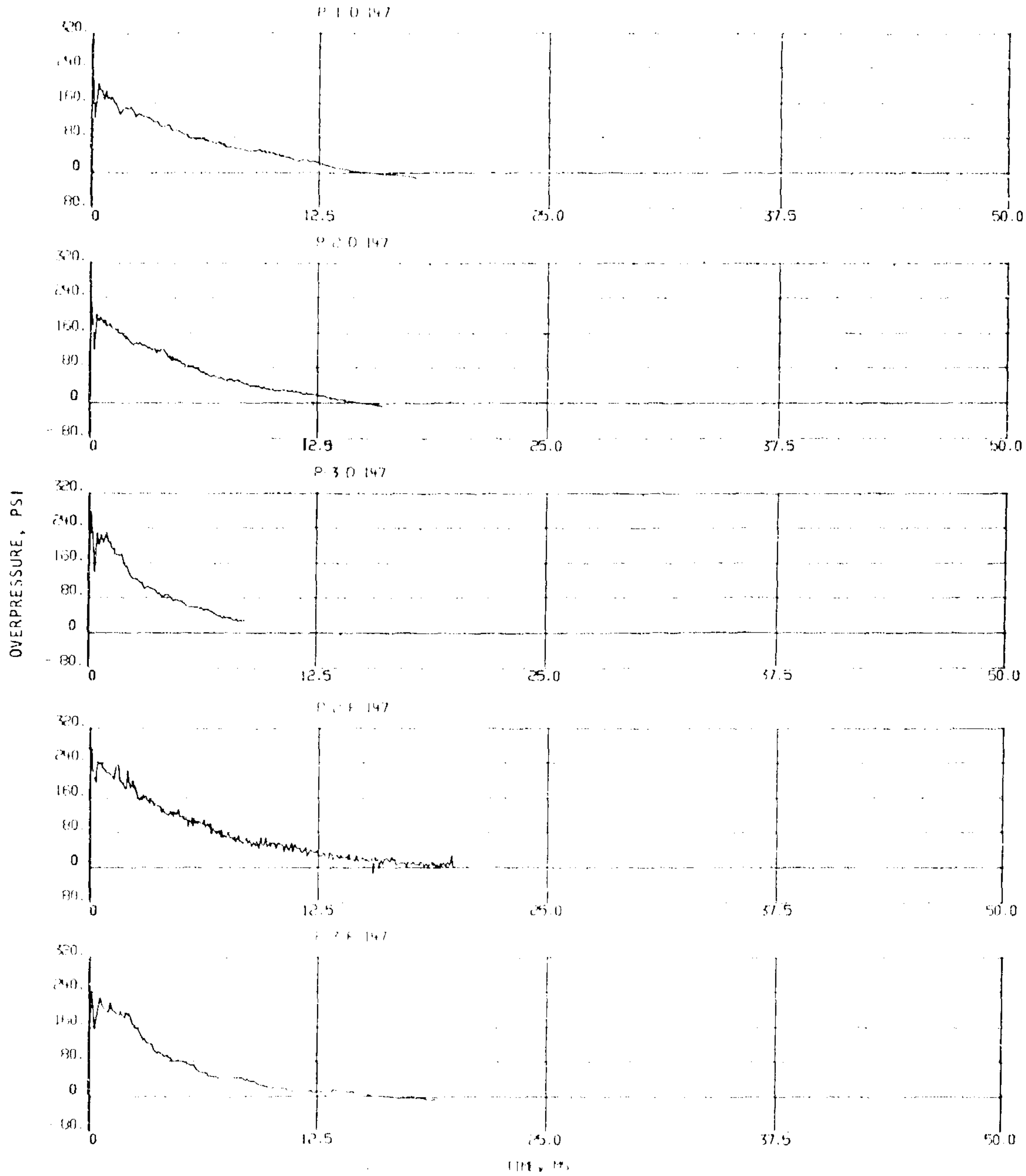


FIGURE 23. Data Plots for Electronic Blast Gauges P-1-D Through P-3-D Located on Wall of Igloo D and for Gauges P-2-E and P-3-E Located on Wall of Igloo E. (The metric equivalents for these plotted data are given in Table 7.)

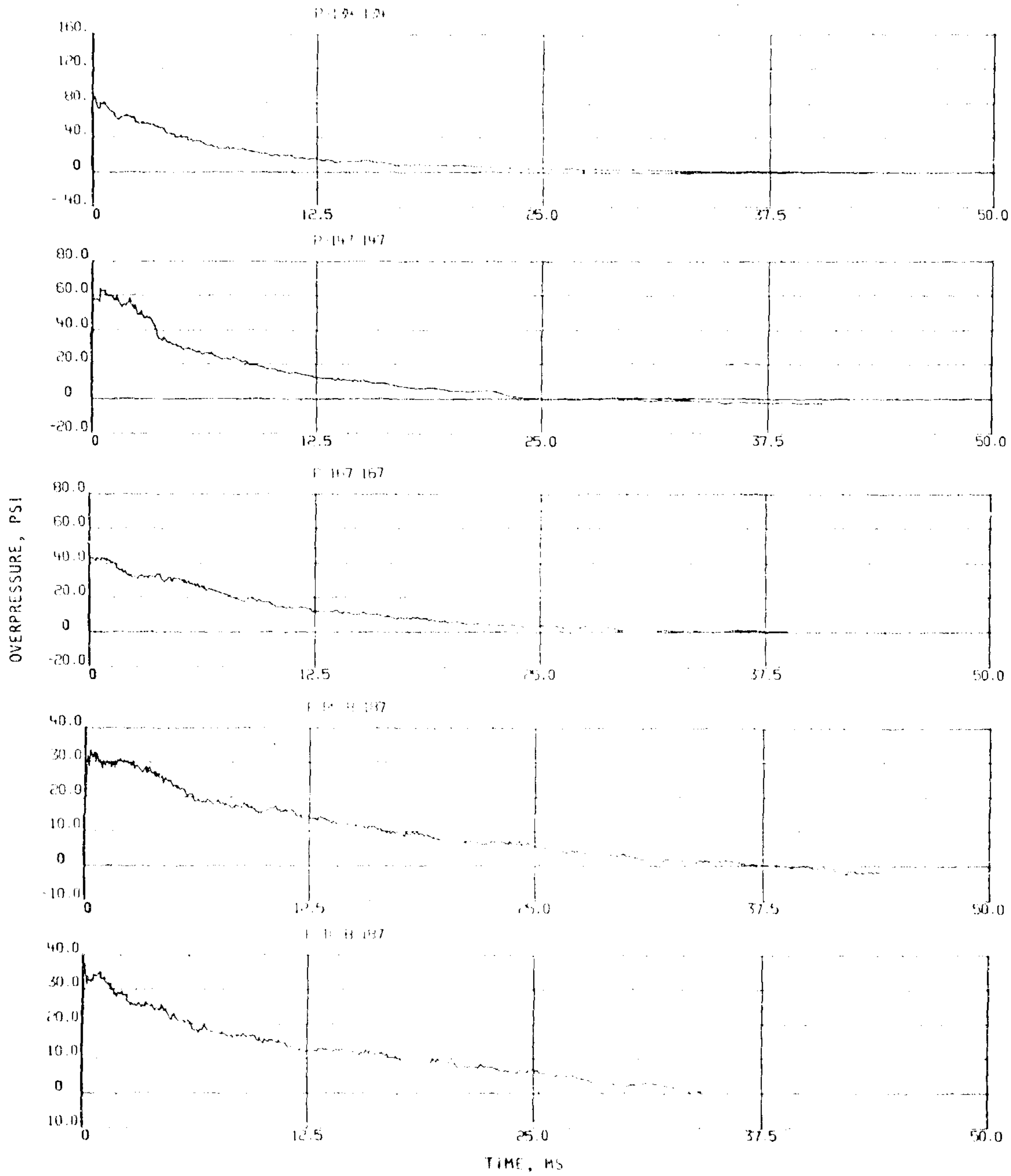


FIGURE 24. Data Plots for Electronic Blast and Air-Pressure Gauges. First three plots are of data recorded at ground level northwest of blast; last two are records of air-pressure gauges in Igloo B earth fill. (The metric equivalents for these plotted data are given in Table 7.)

TABLE 8. Summary of Accelerometer Data, Igloo B.

Position identification	Time of maximum acceleration, ms[a]	Maximum acceleration, g	Time of maximum velocity, ms[a]	Maximum velocity[b]	
				ft/sec	m/s
A-01-B[c]	. . .	. . .	. . .	. . .	. . .
A-02-B	2.5	395	8.5	23.6	7.2
A-03-B	3.1	151	8.0	18.2	5.5
A-04-B	1.7	213	5.5	15.1	4.6
A-05-B	0.4	241	5.3	15.9	4.8
A-06-B	3.3	208	10.3	23.0	7.0
A-07-B	2.5	238	9.6	21.8	6.6
A-08-B	2.8	140	10.0	20.1	6.1
A-09-B	0.6	214	10.0	16.6	5.1
A-10-B	1.9	224	10.3	13.3	4.1
A-11-B	0.3	197	2.8	7.0	2.1
A-12-B	1.5	142	4.1	9.1	2.8

[a] Elapsed time from first indication of accelerometer motion to event described.

[b] Velocity was derived from an algebraic summation of positive and negative accelerations multiplied by the time values to the indicated time of maximum velocity in ms.

[c] Record showed many oscillations including three plus peaks and two minus valleys of more than 800 g and with durations from 0.8 to 2.0 ms in the first 10 ms. Record not plotted in Figure 25.

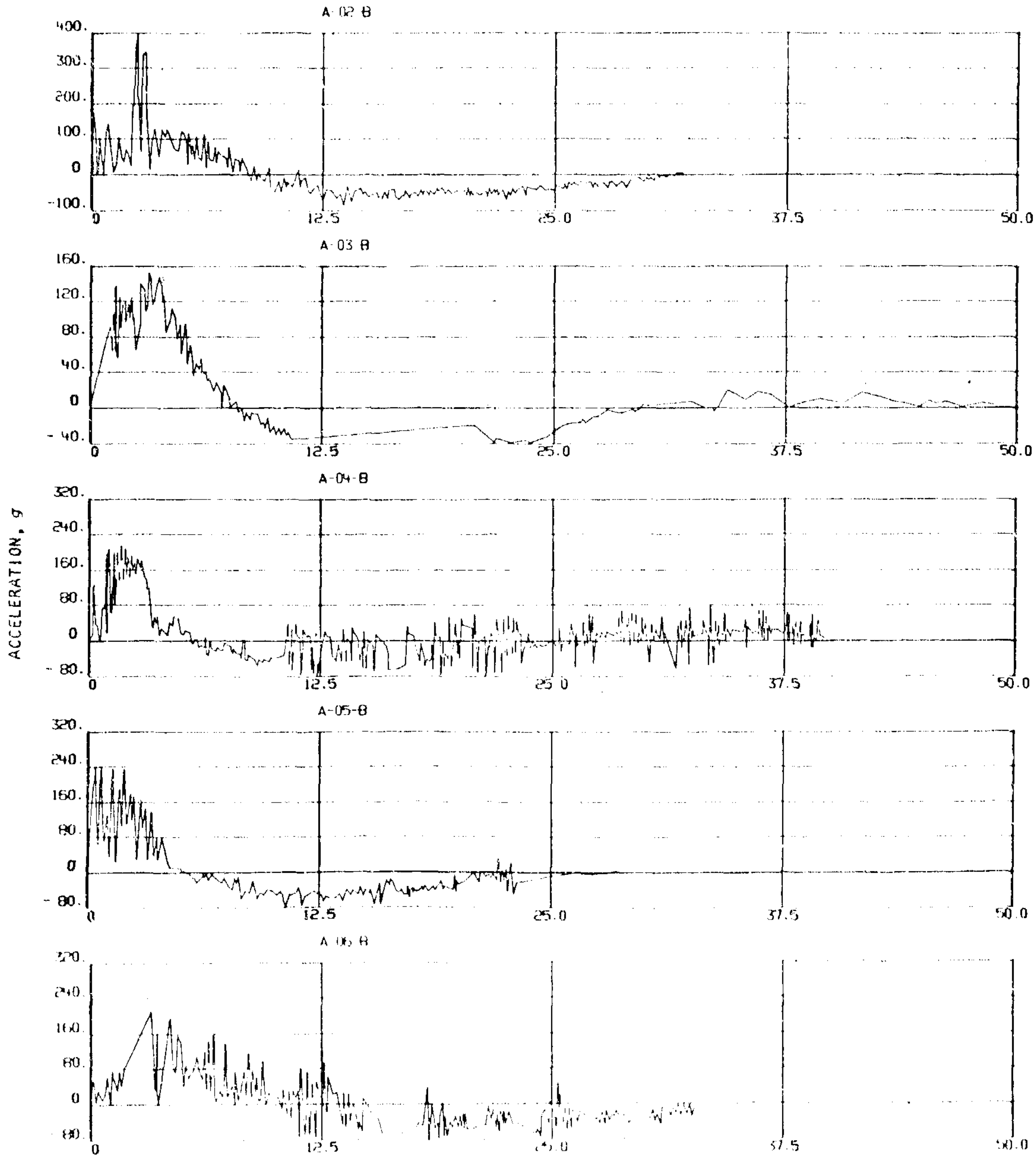


FIGURE 25. Data Plots for Accelerometers A-02-B Through A-06-B Located on Headwall of Igloo B. (The metric equivalents for these plotted data are given in Table 8.)

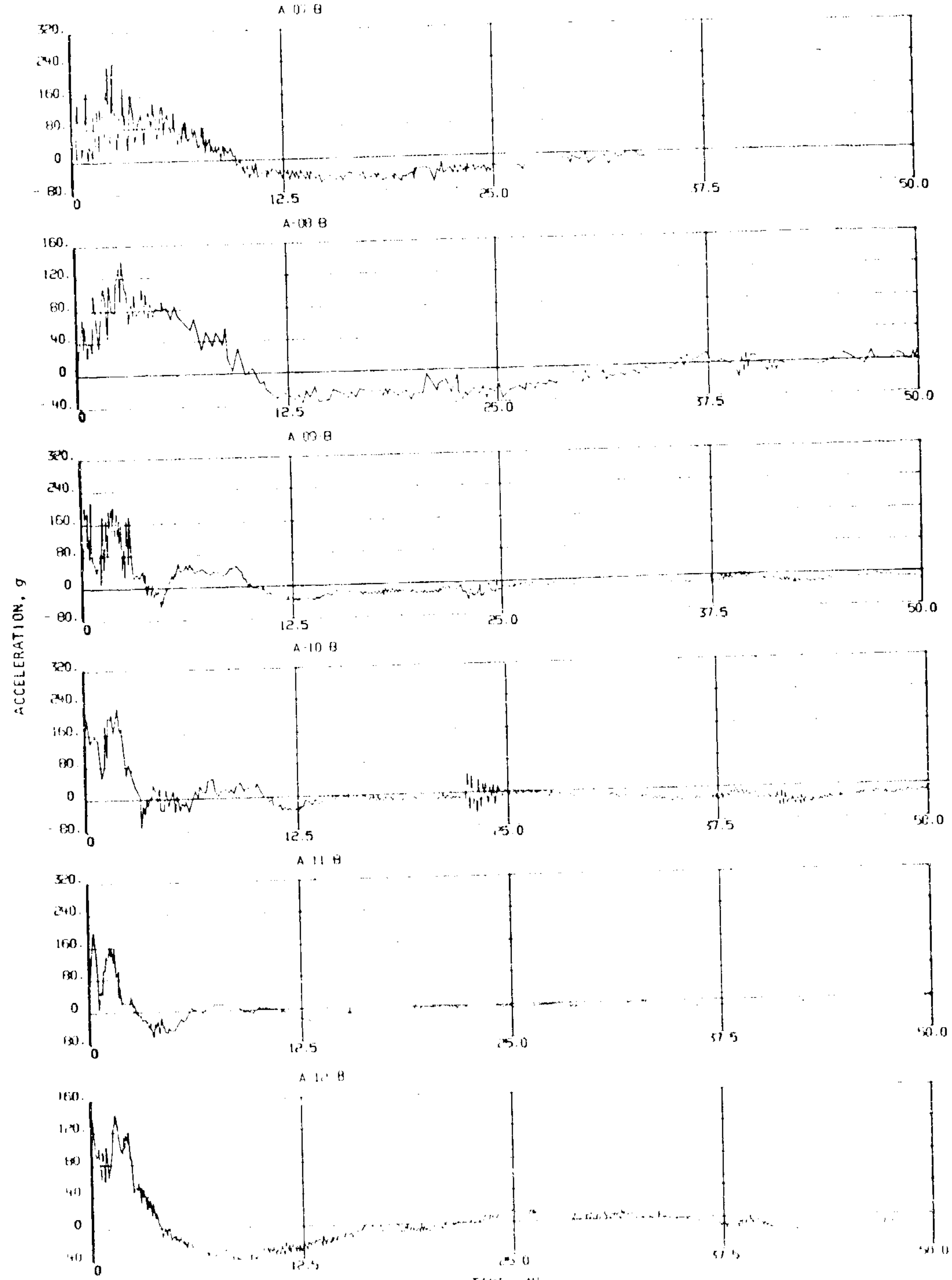


FIGURE 26. Data Plots for Accelerometers A-07-B Through A-12-B Located on Headwall at Igloo B. (The metric equivalents for these plotted data are given in Table 8.)

TABLE 9. Summary of Earth-Pressure Gauge Data.

Distance from center of donor in each case was 187 feet (57 meters).

Position identification	Maximum overpressure		Impulse		Duration, ms
	psi	kPa	psi-ms	kPa-ms	
F-1-B	0.86	5.93	. . .[a]	. . .	. . .[a]
F-2-B	.18	1.24	. . .[a]	. . .	. . .[a]
F-3-B	.36	2.48	1.53	10.6	9.21
F-4-B	0.21	1.45	0.72	4.9	. . .

[a] See Figure 27

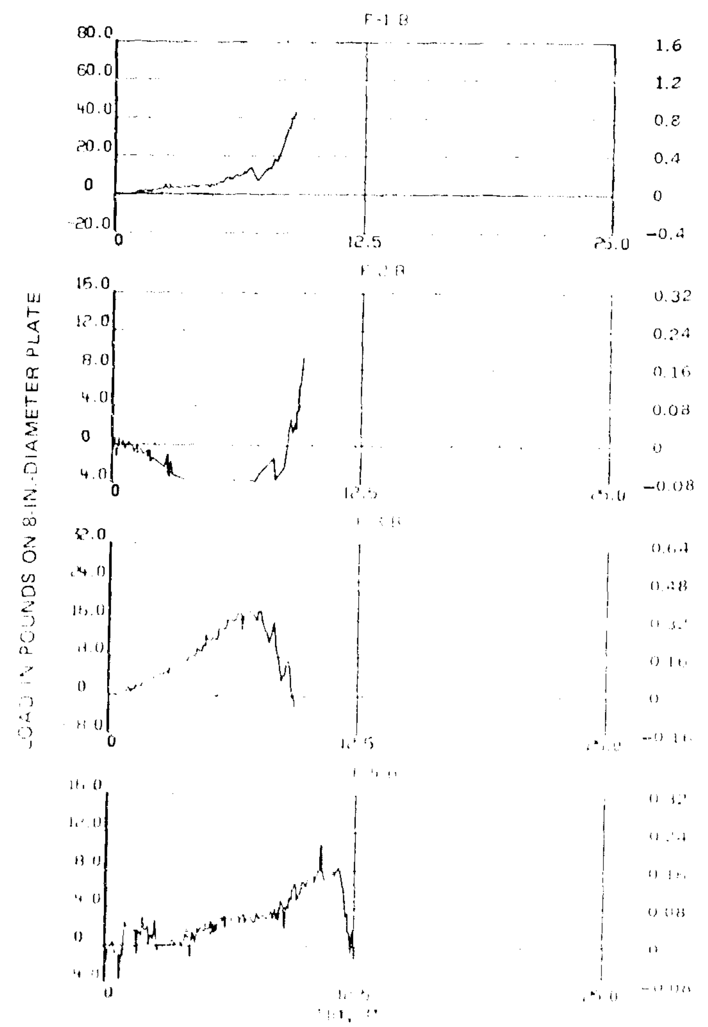


FIGURE 27. Data Plots for Earth-Pressure Gauges on Igloo B. (The metric equivalents for these plotted data are given in Table 9.)

TABLE 10. Summary of Linear Motion Gauge Data.

Position identification	Time, ms[a]	Maximum distance		Maximum velocity	
		in.	mm	ft/sec	m/s
L-1-B	21.65	3.01	76.5	17.5	5.3
L-2-B	18.23	3.22	81.8	18.3	5.6
L-3-B	18.22	2.81	71.4	17.8	5.4
L-4-B[b]	...	...	...	...	...
L-5-B	28.78	3.64	92.5	19.9	6.1
L-6-B	18.72	3.13	80.0	17.8	5.4
L-7-B	17.38	3.29	83.6	24.0	7.3
L-8-B	25.51	4.09	103.9	24.8	7.6
L-9-B	13.48	1.85	47.0	16.2	4.9
L-1-D	12.72	4.83	122.7	36.3	11.1
L-2-D	13.24	4.68	118.9	37.3	11.4
L-3-D	8.55	2.83[c]	71.9	39.1[c]	11.9
L-1-E	10.67	4.83	122.7	52.3	15.9
L-2-E	15.83	4.64	117.9	40.4	12.3
L-3-E	13.36	4.68	118.9	36.8	11.2

NOTE: L-1-B through L-9-B on headwall of Igloo B.
L-1-D through L-3-D on headwall of Igloo D.
L-1-E through L-3-E on headwall of Igloo E.

[a] Time from initial movement to maximum displacement.

[b] No record obtained.

[c] Values are based on initial pulse. Record is not typical after 8.6 ms.

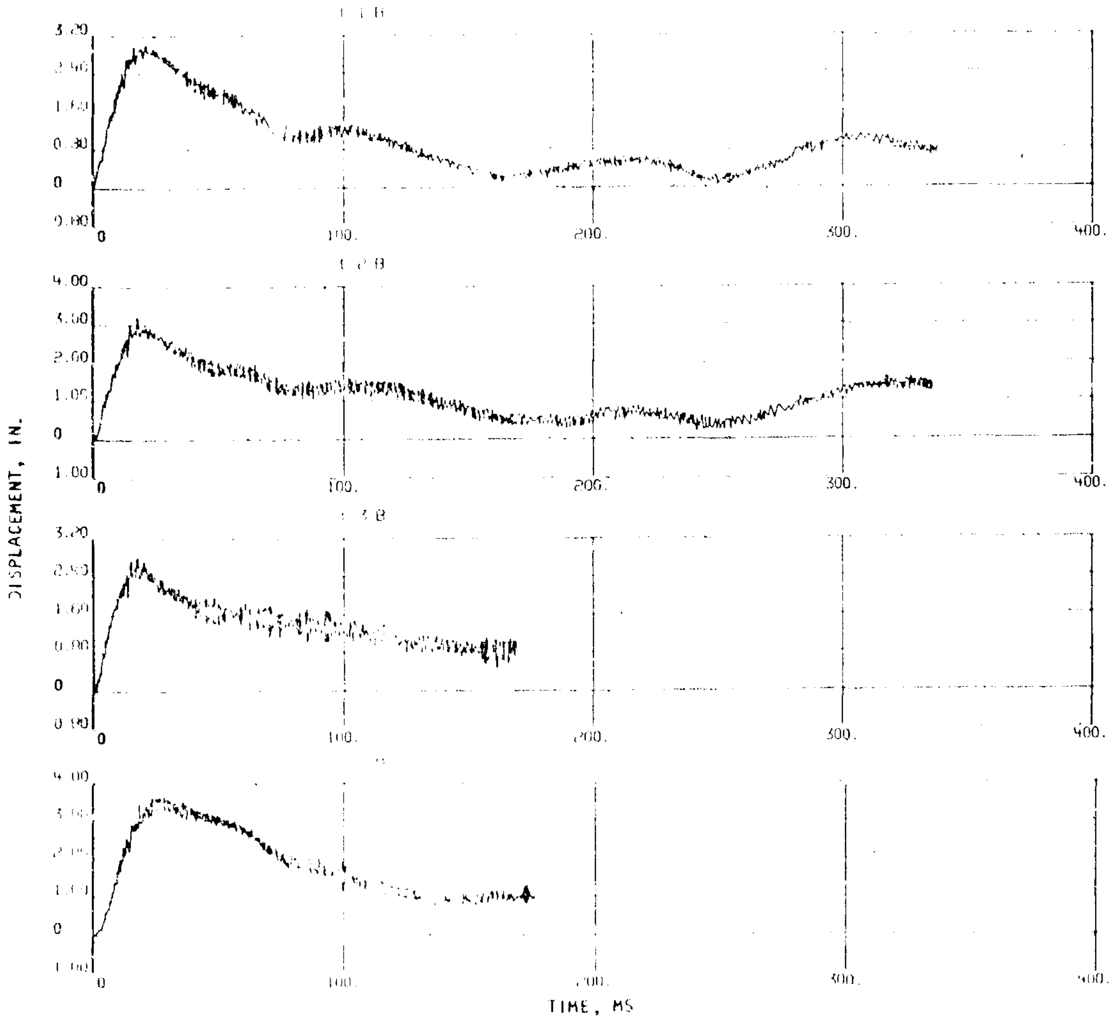


FIGURE 28. Data Plots for Linear Motion Gauges L-1-B Through L-5-B Located on Headwall of Igloo B. No record was obtained for gauge L-4-B. (The metric equivalents for these plotted data are given in Table 10.)

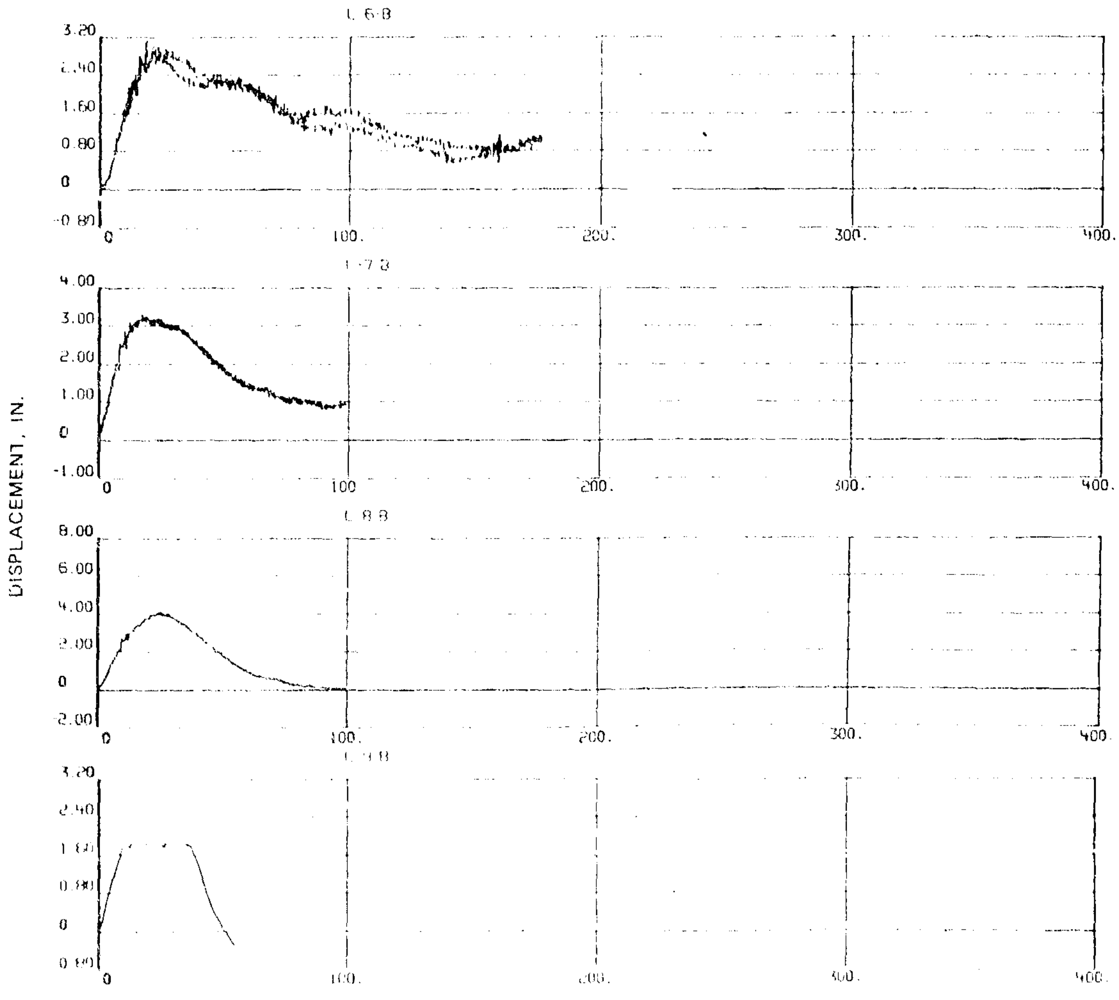


FIGURE 29. Data Plots for Linear Motion Gauges L-6-B Through L-9-B Located on Headwall of Igloo B. (The metric equivalents of these plotted data are given in Table 10.)

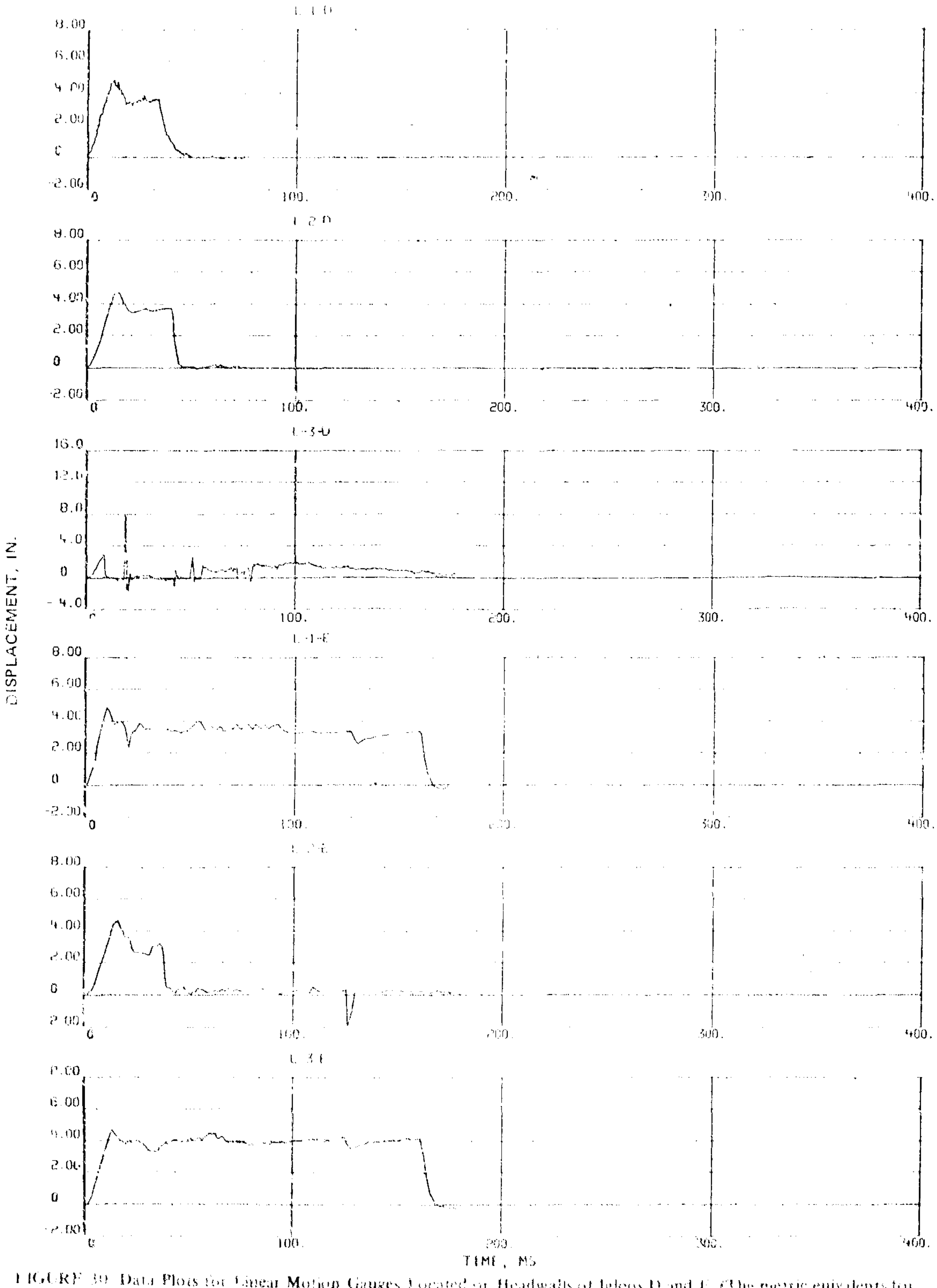


FIGURE 30. Data Plots for Linear Motion Gauges Located on Headwalls of Igloos D and E. (The metric euivalents for these plotted data are given in Table 10.)

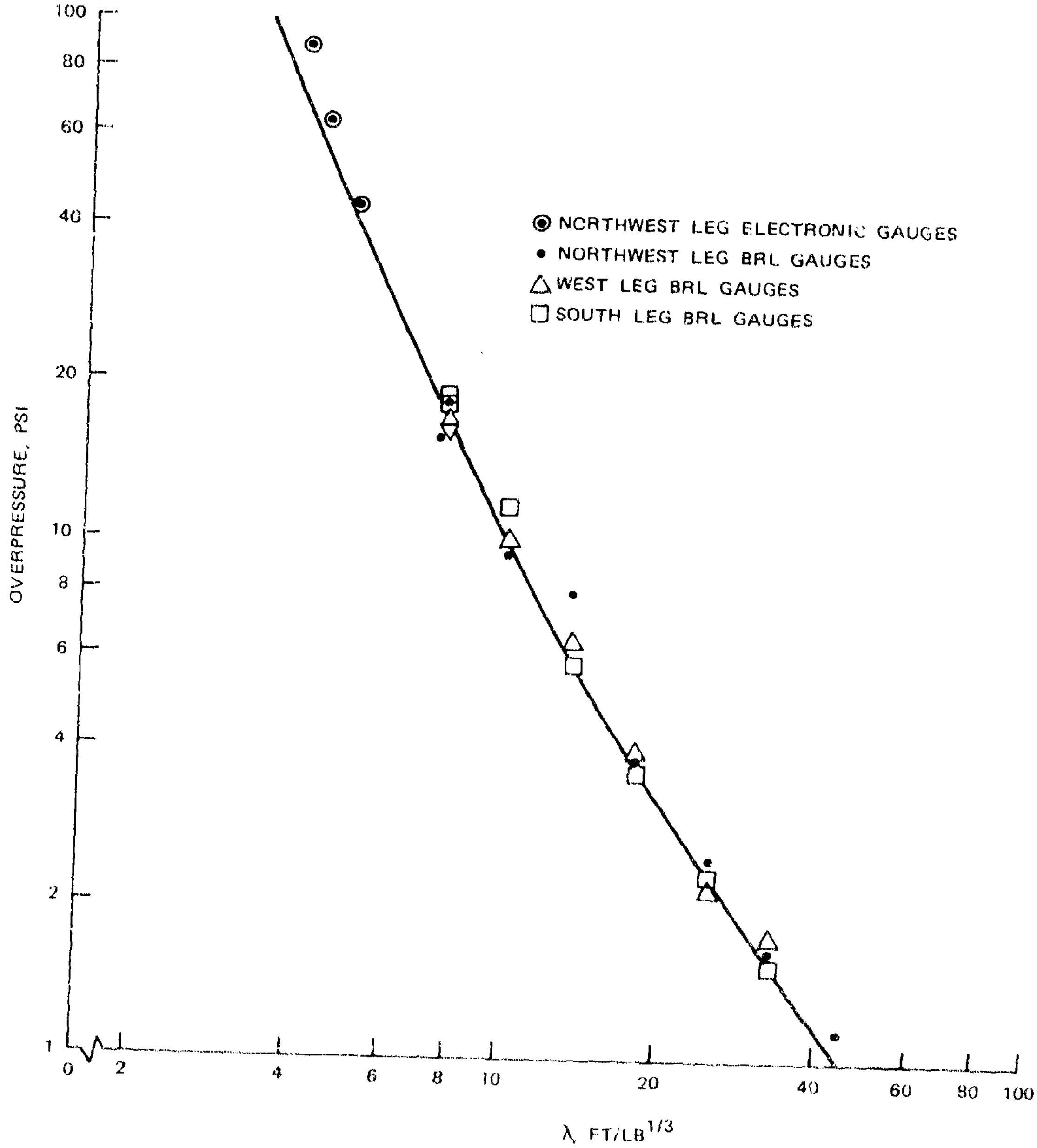


FIGURE 31. Plot of Overpressure Versus Scaled Distance (λ), Comparing ESKIMO IV Blast Data With Standard TNT Blast Data for Hemispherical Charge. (The metric equivalents for data scaled in this plot are given in Tables 6 and 7.)

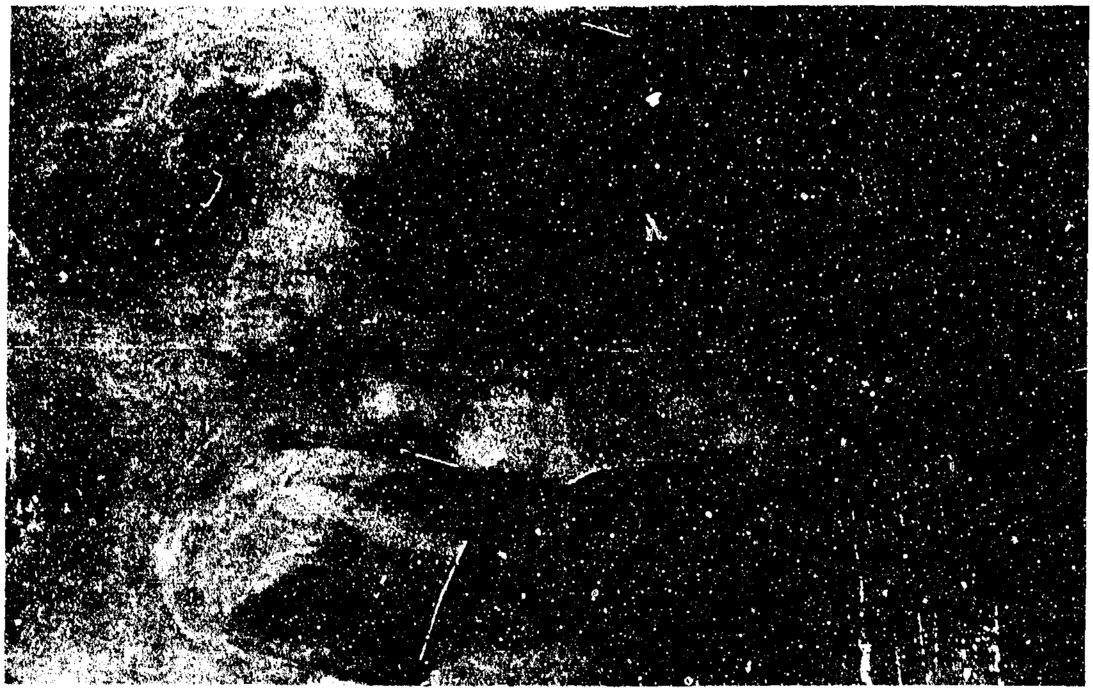


FIGURE 32. Post-Test Aerial View Showing Crater and Discoloration of Surrounding Surface. Igloo E is at top center.

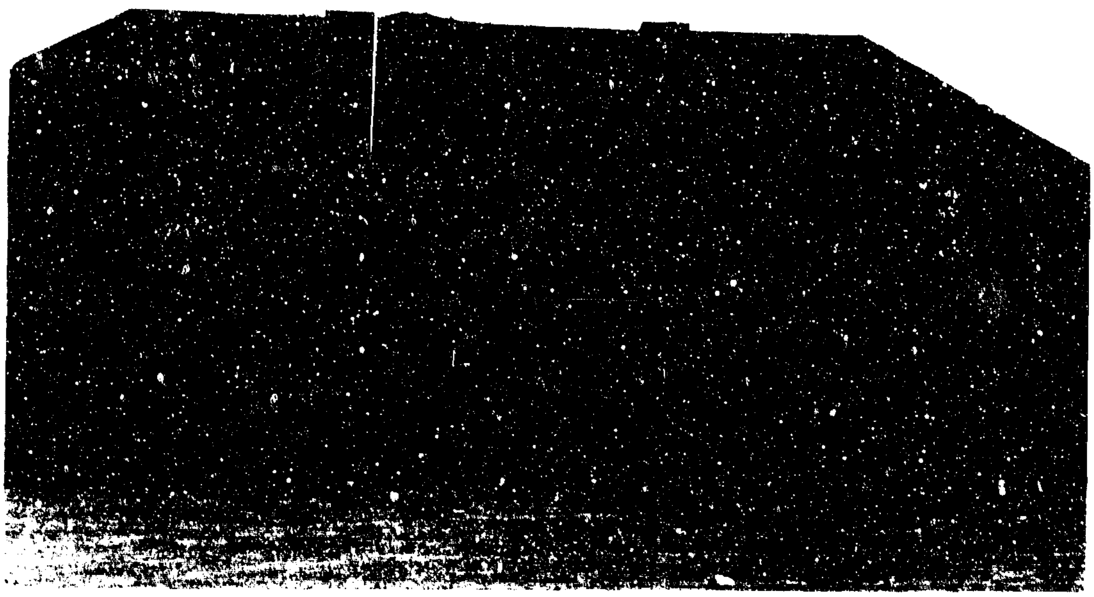


FIGURE 33. Post-Test View of Igloo B Showing Door in Place. (Neg. LHL 189063)

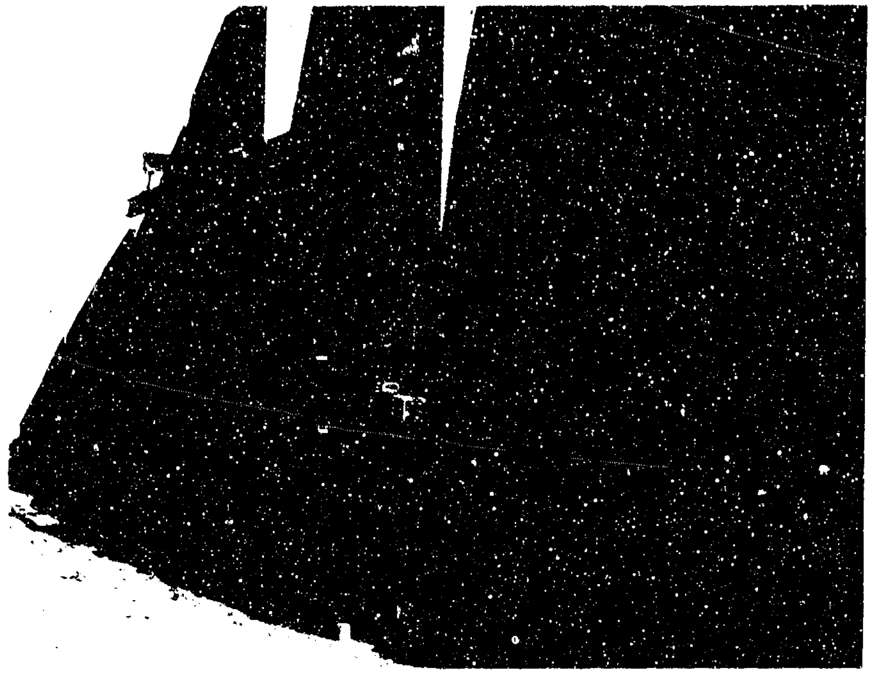


FIGURE 34. Post-Test View of Igloo B Showing Damage to Door. (Neg. LHL 189068)

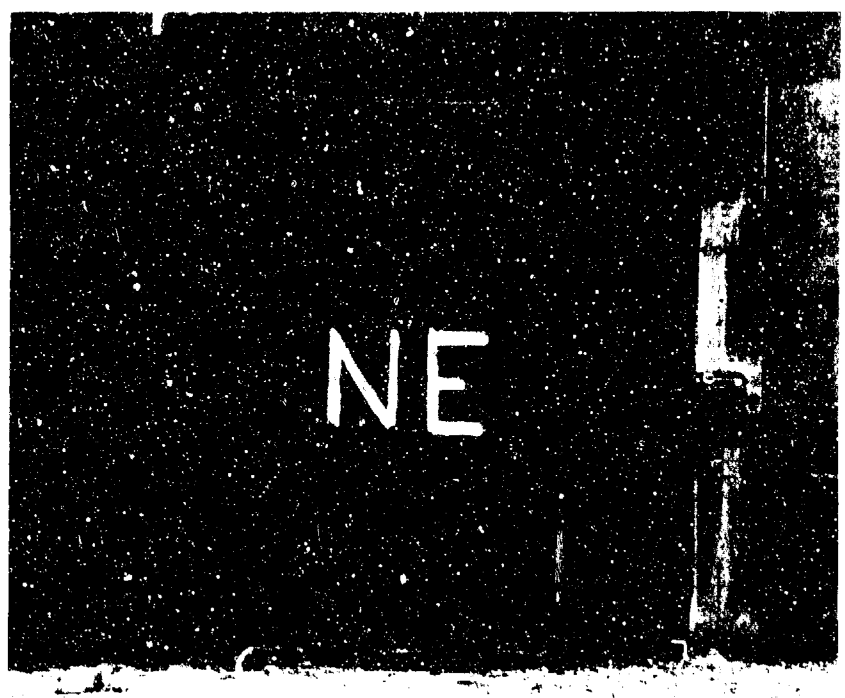


FIGURE 35. Post-Test View of Igloo B Door Showing Deformation. (Neg. LHL 189065)

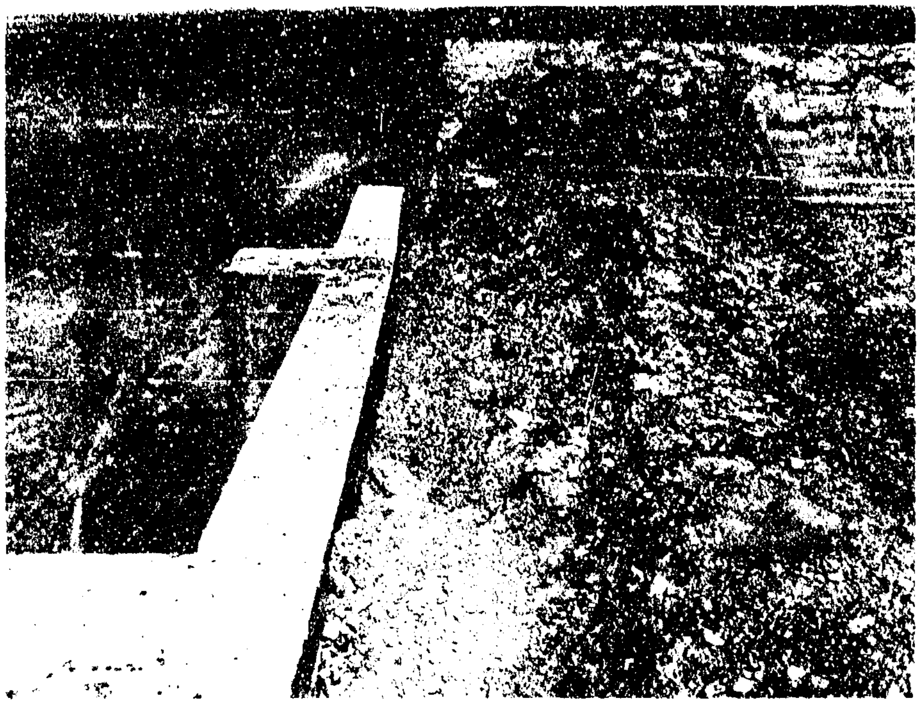


FIGURE 36. Post-Test View of Disturbed Earth Fill Behind Headwall of Igloo B. (Neg. LHL 189248)

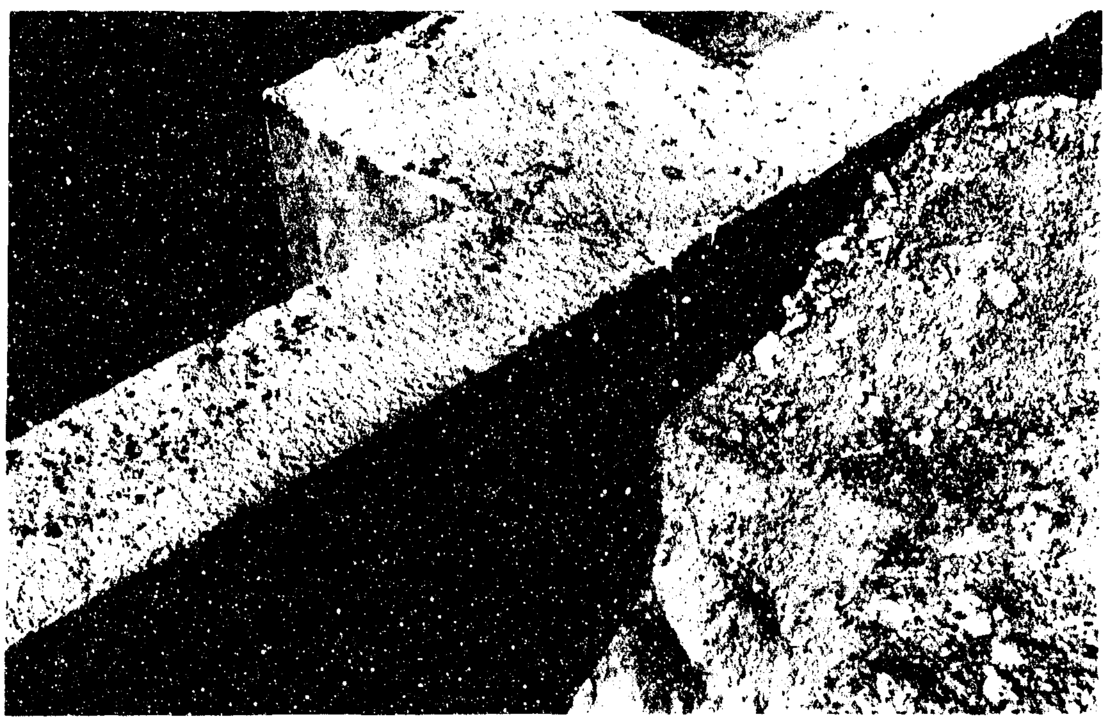


FIGURE 37. Post-Test View of Top of Igloo B Showing Damage to Headwall. (Neg. LHL 189249)

FIGURE 38. Post-Test View of Doorway of Igloo B at Junction With Floor (Neg. LHL 189247)

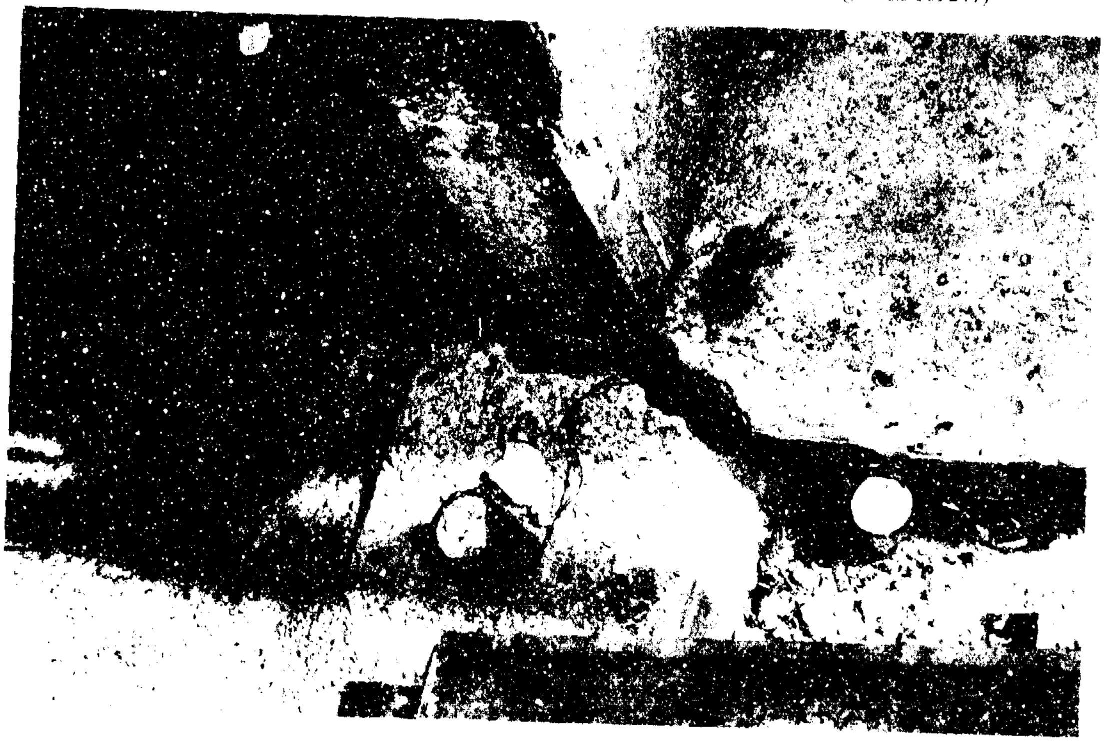


FIGURE 39. Post-Test View of Igloo B Doorway Showing Damage. (Neg. LHL 189246)

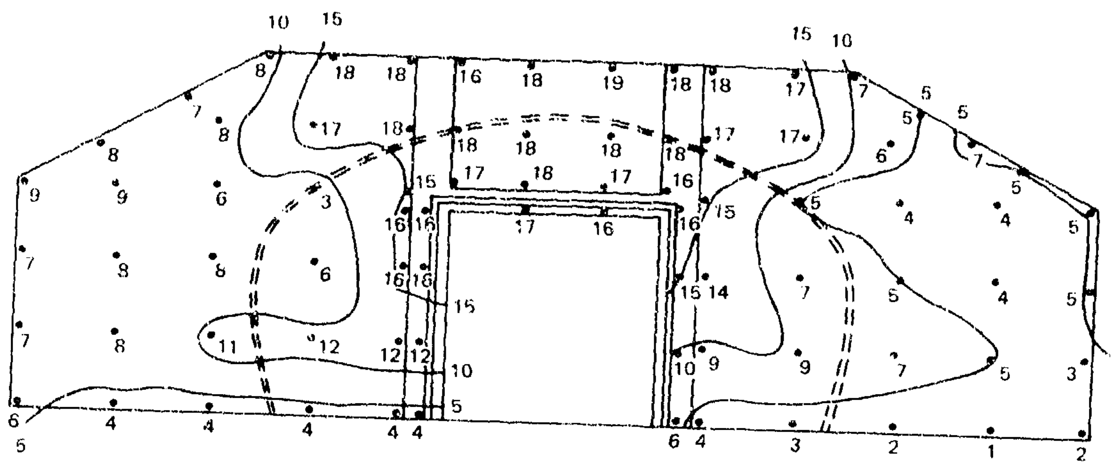


FIGURE 40. Movement of Headwall of Igloo B. All movement is given in hundredths of a foot and is away from the blast. (1/100 foot = 3.05 millimeters.)

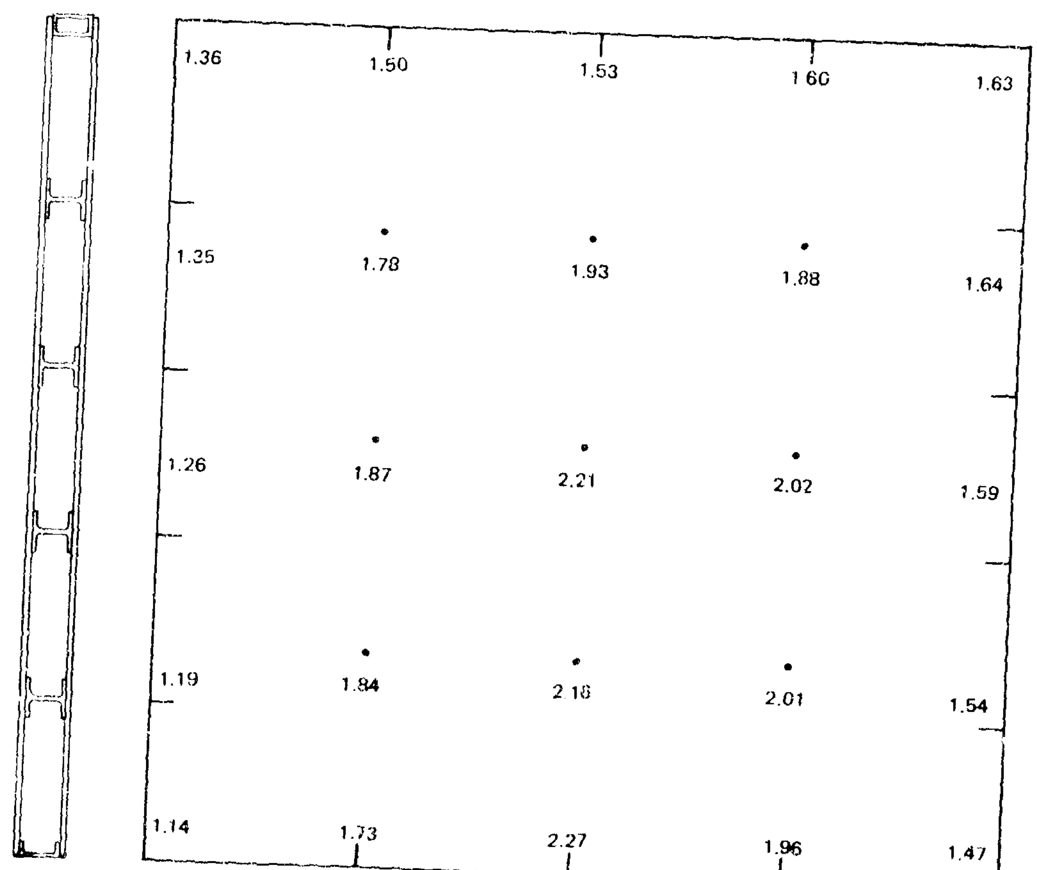


FIGURE 41. Post-Test Static Measurements Made on Door of Igloo B. Values shown are in feet measured from a fixed vertical reference plane approximately 3 feet (0.9 meter) from face of Igloo B headwall. (1 foot = 0.305 meter.)

FIGURE 42. Close-up View of Igloo D Showing Collapsed Door. Pool of water in front of doorway is the result of rainfall the day before the test. (Neg. LHL 189076)

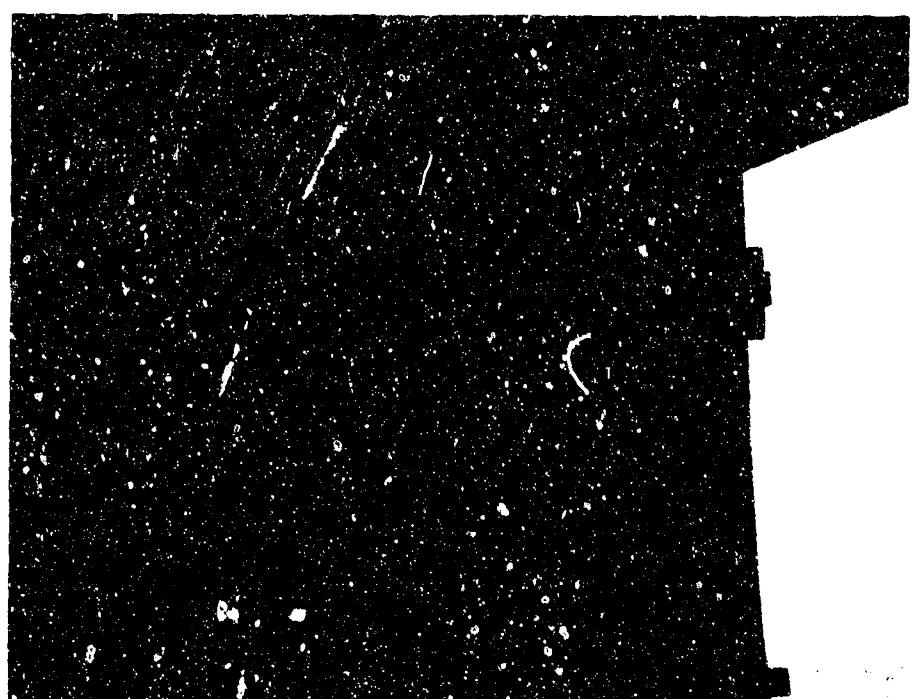


FIGURE 43. View Showing Cracks Above Door Inside Igloo D. (Neg. LHL 189271)

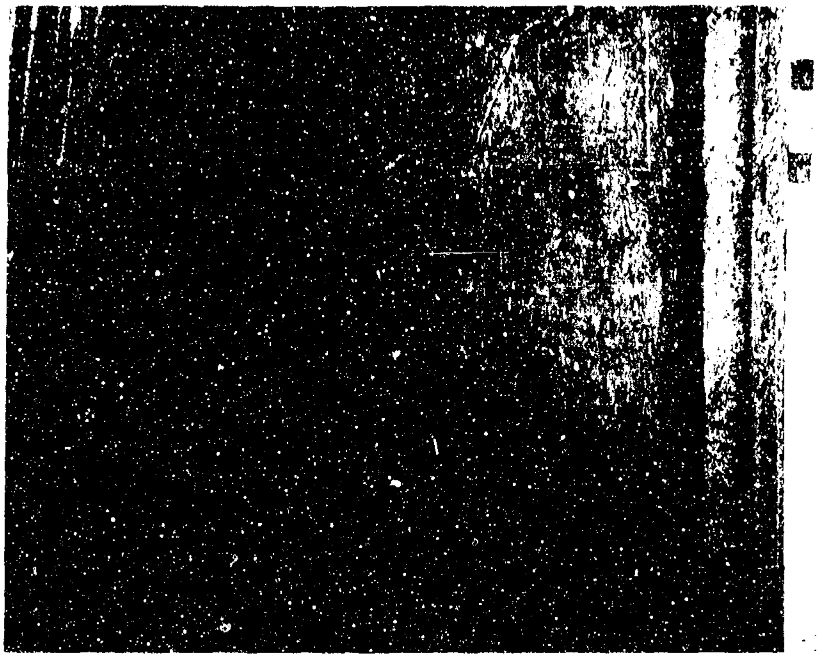


FIGURE 44. Cracks on Inside Surface of Headwall in Igloo D. (Neg. LHL 189272)

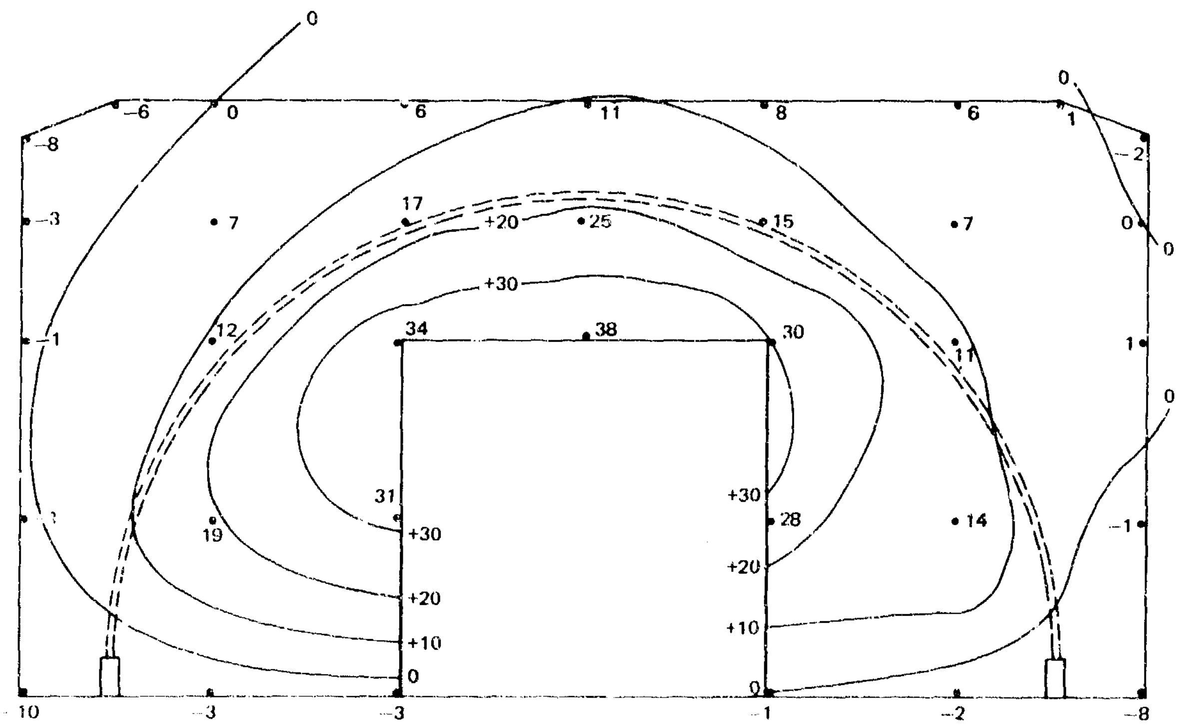


FIGURE 45. Movement of Headwall in Igloo D. All movement is given in hundredths of a foot. Negative values indicate movement toward blast; all others indicate movement away from blast. (1/100 foot = 3.05 millimeters.)

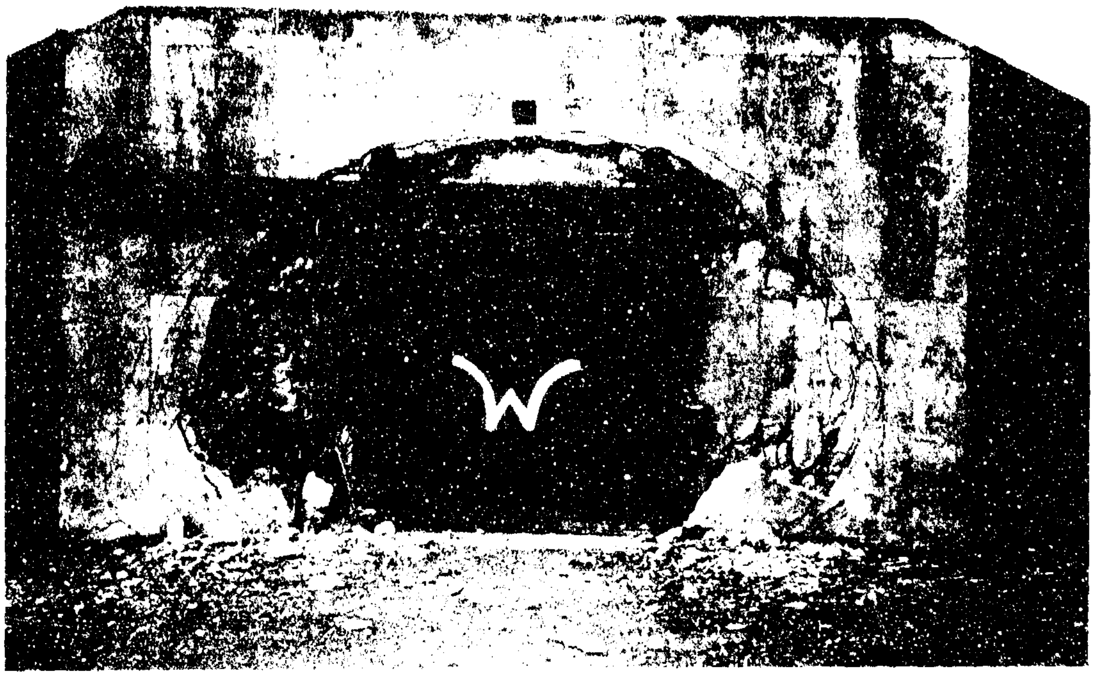


FIGURE 46. Face of [illegible] After Detonation. (Neg. LBL 189056)

FIGURE 47. View of [illegible] Door and Headwall. (Neg. LBL 189061)

FIGURE 48. Close-up of Igloo E Showing Damage to Door and Headwall. (Neg. LHL 189060)

FIGURE 49. View Inside Igloo E Showing Damage to Right Side of Headwall. (Neg. LHL [illegible])

FIGURE 50. View Inside Igloo E Showing Damage to Left Side of Headwall. Door has been removed. (Neg. LHL 189275)

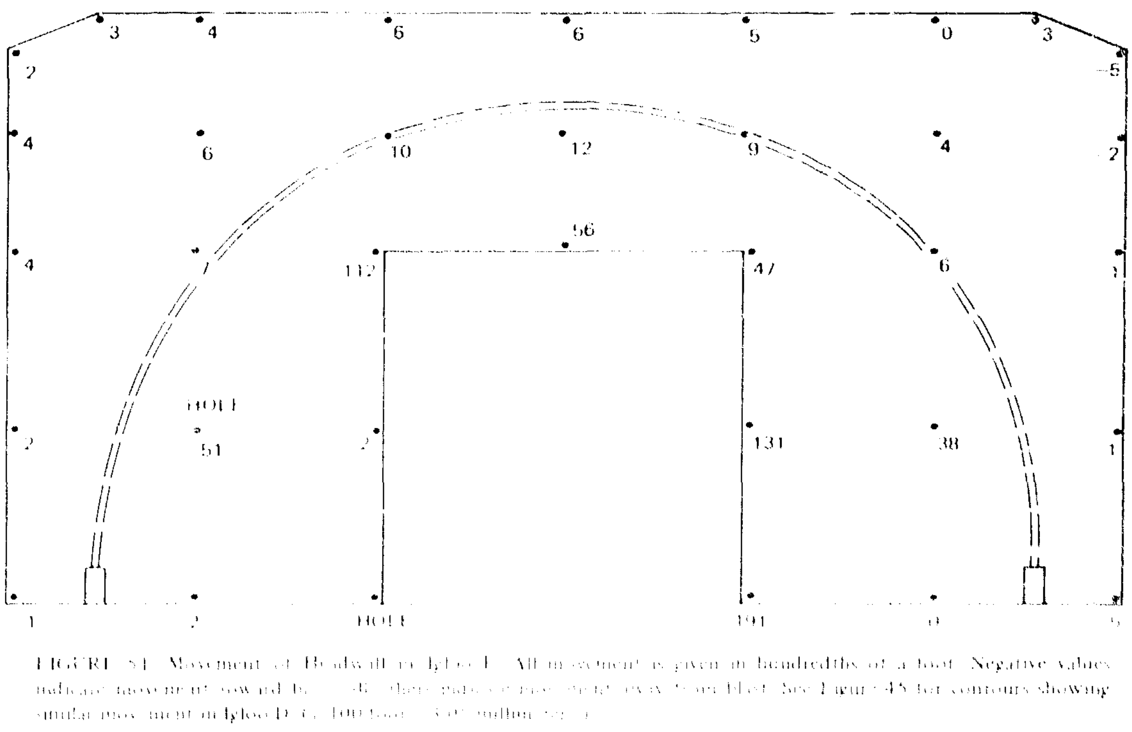


FIGURE 51. Movement of Headwall in Igloo E. All movement is given in hundredths of a foot. Negative values indicate movement toward [illegible]; other [illegible] away from blast. See Figure 45 for contours showing similar movement in Igloo D [illegible] 100 feet [illegible] million [illegible]

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   SPSS, Dr. E. Sevin (1)
[illegible] Explosives Safety Board

1 Energy Research and Development Administration, Albuquerque (ODI)

1 Energy Research and Development Administration, Washington (Carlo Ferrare, Jr.)

1 Bureau of Mines, Pittsburgh (Dr. Robert W. Van Dolah, Research Director, Pittsburgh Mining & Safety Research Center)

1 Agbabian Associates, El Segundo, CA (Dr. D. P. Reddy)

1 Black & Veatch Consulting Engineers, Kansas City, MO (H. L. Callahan)

1 Institute of Makers of Explosives, New York, NY (Harry Hampton)

1 Lovelace Foundation, Albuquerque, NM (Dr. E. R. Fletcher)

1 Mason & Hanger-Silas Mason Co., Inc., Amarillo, TX (Director of Development)